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ELECTRICITY

AND THE

ELECTRIC TELEGRAPH.

BY

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SEVENTH EDITION, REVISED AND ENLARGED.

WITH 670 ILLUSTRATIONS.

IN TWO VOLUMES.

VOL. I.

NEW YORK:
D. APPLETON AND COMPANY.
1888.

RUSSELL BROTHERS, PRINTERS,
17 TO 23 ROSE ST., N. Y.

PREFACE.

The object which has been aimed at in the preparation of the present work has been to furnish a treatise on the subject of Electricity and the Telegraph, which should present a comprehensive and accurate summary of the present advanced state of the science and art, both in this country and abroad, and at the same time serve a useful purpose as a manual for the information and guidance of those engaged in the different branches of the telegraphic service. No pains have been spared to render the work complete, as well as historically and descriptively accurate. With this view every available means of information has been resorted to, and all the existing literature relating to the subject has been carefully examined. Especial attention has been paid to the voluminous contributions of Germany, a nation whose electricians unquestionably occupy the foremost rank among discoverers and inventors, but whose labors, although lying at the foundation of many of the most brilliant achievements of modern telegraphy, have heretofore remained, for the most part, unknown to the English reader. The discoveries, inventions and practical improvements of the past few years, especially those relating to the duplex and quadruplex methods of transmission, and to the improved type-printing apparatus, which in America have almost revolutionized the telegraphic service, are now described and illustrated for the first time with a completeness commensurate with the great importance of the subject.

The value of the descriptive portion of the work has been

greatly enhanced by the introduction of numerous original illustrations of high artistic merit, which have been freely employed whenever they could be made to serve a useful purpose in the elucidation of the text.

It is hoped that the work will be found to be of a character which will render it acceptable, not merely to the professional telegraphist, but to all who are in any way interested in the progress of electrical science, and in its various applications to the useful arts.

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ELECTRICITY AND THE ELECTRIC TELEGRAPH.

CHAPTER I.

FRICTIONAL ELECTRICITY.

By the friction of two bodies of different natures they acquire the property of attracting fragments of paper, feathers, and similar substances. The power thus manifested is called electricity, a name derived from the Greek word ἤλεκτρον, signifying amber, the first substance upon which electrical properties were observed.

Fig. 1.

If a ball made from the pith of elder, about a quarter of an inch in diameter (fig. 1), be suspended by a fine silk thread, and a glass tube rubbed with dry silk be brought near it, the ball will be first attracted and then repelled. If the tube be brought into contact successively with two pith balls thus suspended, and the balls be placed near each other, they will repel each other.

These effects are explained by supposing that there has been excited upon the glass tube a subtle fluid which is self-repulsive; that by touching the balls a portion of this fluid has been imparted to them, which is diffused over their surface, and which cannot escape by the silk thread; that the fluid remaining on the glass tube repels the fluid diffused on the balls, and therefore repels the balls themselves; and also that the fluid diffused on the one ball repels the fluid diffused on the other ball, and the balls being covered by the fluid repel each other.

If we take two pith balls, one of which has been electrified by contact with a glass rod rubbed with silk, and the other by a rod of sealing wax rubbed with fur or flannel, we shall find that the ball which has been repelled by the glass tube will be attracted by the sealing wax, while the one repelled by the sealing wax will be attracted by the glass.

The electricity evolved from the glass is, therefore, not identical with that evolved from resins, since the one attracts what the other repels, and hence it has been inferred that there are two electric fluids. That which is obtained from a glass rod rubbed with silk has been called vitreous electricity, and that which is obtained from sealing wax rubbed with fur is called resinous electricity.

When electricity is produced equal quantities of vitreous and resinous electricity are produced, for although the glass when rubbed becomes vitreously electrified only, the material with which it is rubbed becomes resinously electrified, and the quantity on the glass is precisely equal and opposite to that upon the rubber.

This fact has led some to conclude that there is but one electric fluid, and that all bodies in their natural state have always

a certain amount, the repulsive effect of which is neutralized by the attraction exercised by the body upon it. The effect of friction is supposed to be to deprive the cloth of a portion of its natural charge of electricity, and to charge the glass with what the cloth loses. Accordingly the glass is said to be positively electrified and the cloth negatively electrified. Although the hypothesis of a single fluid has not been adopted, the terms positive and negative electricity are now almost universally substituted for vitreous and resinous electricity. These terms, although meaningless as applied to two similar affections of matter, have the advantage of being definite, and of having no reference to the source whence the electricity originates. They admit, moreover, of a very convenient contraction by the use of the algebraic sign $+$ for positive, and $-$ for negative.

Whenever two bodies are rubbed together and electricity is developed, one body is charged with positive electricity and the other with negative electricity; but the kind of electricity which each substance acquires depends upon the substance against which it is rubbed. Thus glass rubbed with silk or flannel become positively electrified, and when rubbed with a cat skin it becomes negatively electrified. The positive or negative electrification of the material does not depend absolutely on the substance of that material, but depends on some peculiar relation between the two substances in contact.

If a glass tube is rubbed with silk and is then brought in contact with a pith ball suspended by a silk thread, the ball will be repelled by the tube and by all other bodies charged with positive electricity, while it will be attracted by all bodies charged with negative electricity. Hence it is easy to determine which kind of electricity is furnished by a given body.

Electricity moves over some bodies with the greatest freedom, and over others with the greatest difficulty. The former class of bodies are called conductors, and the latter non-conductors or insulators. Of all bodies the metals are the best conductors, while vitreous and resinous substances are the poorest conductors, or insulators. Between these two categories of bodies there

are other matters, such as steam, vapor, charcoal, and similar substances which are medium conductors. All matters may be classified by placing them in order according to their conductibility, the metals occupying the first rank, and glass and resin the last. There is no substance known which is perfectly impervious to electricity, for the pressure or potentiality of the electricity may be so increased as to force it, for a certain distance, through all bodies; neither is there any body which opposes no resistance to the transmission of electricity.

Good non-conductors are called insulators because when a body supported by a non-conductor is charged with electricity the charge cannot escape. Thus if a globe of metal supported on a glass pillar, or suspended by a silk cord, be charged with electricity it will retain the charge; whereas, if it were supported on a metallic pillar the electricity would pass away over the surface of the pillar.

An electrified body is said to be insulated when its connection with other bodies is formed by means of non-conductors. Dry air is a non-conductor; but water is a conductor, and the presence of vapor in the air impairs its insulating power.

CHAPTER II.

STATIC INDUCTION.

ELECTRICITY has the power of inducing neighboring bodies to assume a peculiar electrical condition without being in contact with them, which is termed induction.

When an insulated conductor (*a*, *b*, fig. 2) is approached by a body (R) charged with + electricity it becomes likewise temporarily electrified. The + electricity of R attracts the — electricity of *a b*, and repels the + electricity of *a b*, so as to separate them, drawing the — fluid toward the nearer end, and repelling

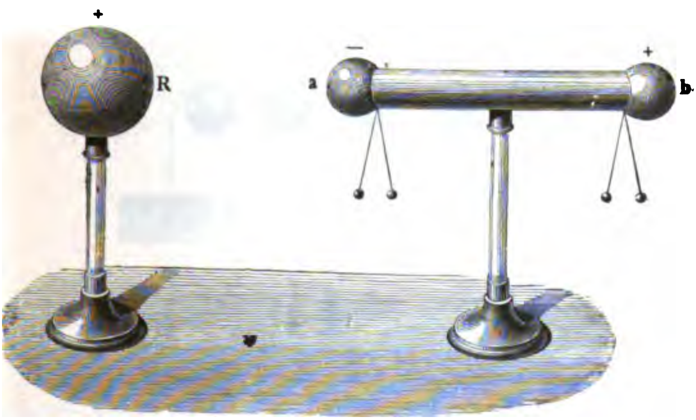


Fig. 2.

the + fluid toward the remote end. If a pair of pith balls be suspended from each end of the cylinder the balls will diverge, but a pair suspended from the centre will not diverge.

By means of an electroscope, consisting of a small ball of the pith of elder suspended by a silk thread (Fig. 1), we may ascertain that on that end of the cylinder wheih is nearest to R the electricity is —, and on that end which is most remote from R the electricity is +.

If the charged body R had been negatively electrified, the end *a* would have become positively and the end *b* negatively electrified.

The electricity produced in this case at *a b* is not caused by R communicating its electricity to the body *a b*, but by the division of the natural, not analyzed, electricity under the influence of the electricity in the neighborhood; whence the designation of static induction, in opposition to the direct communication of electricity, which follows when R is brought in contact with *a b*.

The electricity which is present in the vicinity *a* of the body R is attracted, while, on the contrary, that which is present at the distant end *b* is repelled. When, consequently, the neighboring extreme end *a* is touched, whilst the charged body R remains in the neighborhood of *a b*—the electricity collected there will not be diverted, as will the distant electricity at *b*;

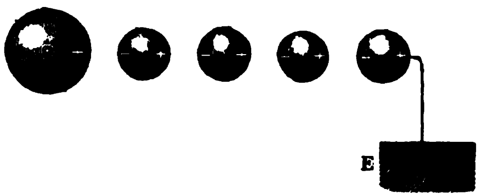


Fig. 3.

whilst the former remains constantly attracted by the opposite one at R the latter is repelled by R at *b*, and, consequently, flees away from it as far as possible. For this reason it is said that the opposite electricity at *a*, which is nearest to the dividing electricity at R, is *bound*, while its correspondent at *b* is *free*.

That the + electricity at the further half of the cylinder *a b* is as free and insulated as if no — electricity existed on the other half, is shown by placing a cylinder near the first, forming a combination of it as it were, without touching, when the second cylinder, under the induction of the + electricity of the first, is thrown into the same state as the first. This second can induce the same state in a third (fig. 3), and so on. When the charged ball is withdrawn the whole series return to their natural con-

dition, without being in any way permanently affected. The moment, however, it is again brought near, each cylinder becomes again polarized, and there is manifested at the further extremity of the last a + electricity, which would exert the same influence on a body connected with the ground as if a portion of the electricity of such a body had been actually communicated or transferred to it.

The amount of the electricity induced by an electrified body on surrounding conductors, is equal and opposite to that of the inducing body. Faraday proved this by the following beautiful experiment: He insulated an ice pail (fig. 4), ten and a half

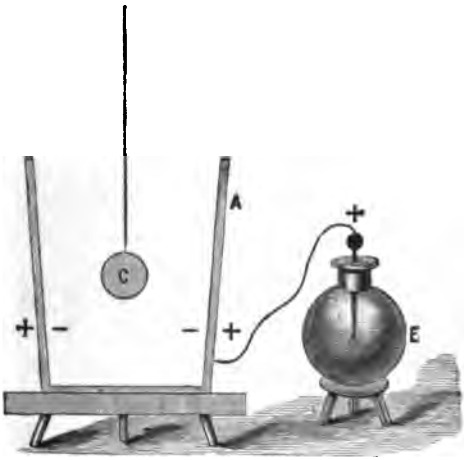


Fig. 4.

inches high and seven inches in diameter, and placed the outside of it in conducting connection with the knob of a gold leaf electroscope (E). A round brass ball (C) suspended by a long dry thread of white silk, was charged with + electricity, and introduced within the pail. The pail was thus subjected to polarization—the induced — electricity being on the inner and the + electricity on the outer surface. The divergence of the leaves, caused by the induced + electricity, increased as the ball was lowered, until it sunk three inches below the opening,

when they remained steadily at the same point. The ball was lowered till it touched the bottom and communicated its charge to the pail, when the leaves remained in the same state as before. The ball, when lifted out, was found to be fully discharged, showing that the + electricity developed by induction on the outer surface was exactly the same in amount as that of the ball itself. The — electricity of the inside of the pail being equal to the + electricity on the outside, was, therefore, equal to the + electricity of the ball, but opposite in kind. He altered the experiment so as to have four insulated pails inside each other, and the effect on the outmost pail was in no way altered. No force was lost in the transmission from one pail to the other. We may conclude from this experiment that, on the walls of a room or other conductors surrounding the charged body, the total amount of opposite electricity induced is equal in amount to that of the body itself.

If, when the electricity of the cylinder *a b* (fig. 2) has been decomposed by the action of R, we touch with the finger the remote end *b*, the + electricity which was driven to that part of the conductor will be conveyed away, but the — electricity in the other end will remain, being retained in its place by the attraction of the opposite electricity in R. The self-repellency of the electricity in R is thus neutralized by the attraction of *a b*; and, if the sphere R communicate with some source of electricity, more of the fluid will pass into it. This will decompose more of the natural electricities of *a b*, attracting the — and repelling the +. If we touch with the finger the remote end *b*, the + electricity will be conveyed away, but the — electricity of the nearest end will remain, being held in its place by the attraction of the opposite electricity in R. This allows more electricity to pass into R, which again reacts on *a b*; and thus, by the influence of induction, the electricity, proceeding from a feeble source, may acquire considerable power.

The electricity thus accumulated on R and *a b* exhibits but little repulsive force, because the self-repellency of either fluid is neutralized by the attraction of the opposite fluid in the other

conductor. Electricity in this condition is said to be disguised. But, if we remove the conductor *a b* from the vicinity of R, the repulsive force of the fluid is immediately exhibited, and the body appears powerfully charged with electricity.

When the electricity of a body R thus acts by induction upon an unelectrified body *a b*, the body *a b* is attracted by R, because the attraction of R for the opposite electricity in the nearer end of *a b* is greater than its repulsion for the same kind of electricity in the remote end of *a b*, the action in the latter case being enfeebled by distance. Hence, we see why an unelectrified body is attracted by an electrified body. The two electricities residing on the unelectrified body, and which in their natural state neutralize each other, are first decomposed, and the opposite electricity is drawn to the end nearest to the electrified body, when attraction between the two bodies necessarily results.

CHAPTER III.

ELECTRICAL MACHINES.

AN electrical machine is an apparatus for conveniently developing and accumulating electricity, and consists of three principal parts—viz., the body on which the electricity is evolved, which is generally a glass cylinder or plate; the rubber, consisting of a hair cushion; and an insulated conductor, to which

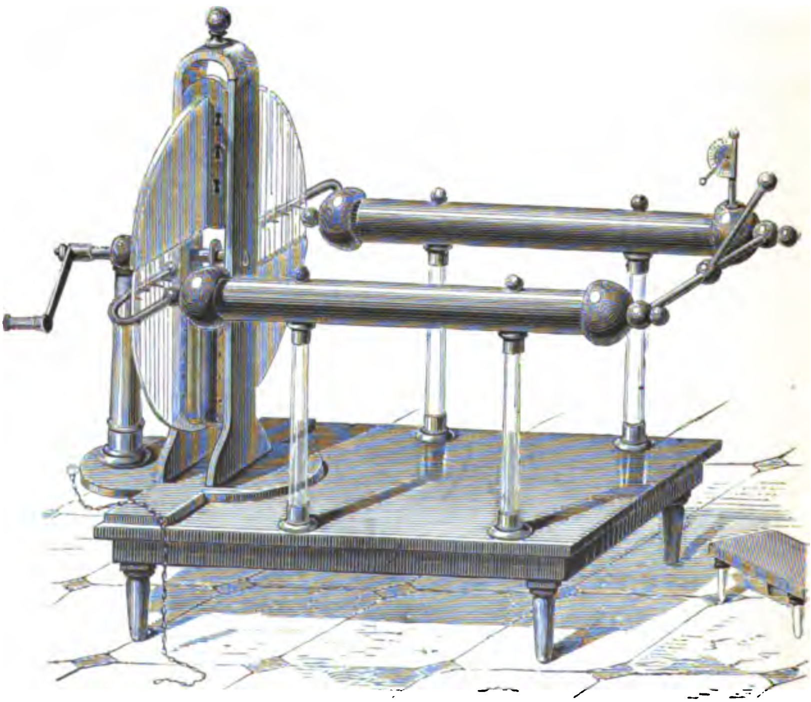


Fig. 5.

the electricity is transferred, and on which it is accumulated. The plate machine is now generally preferred to any other form.

The most usual form of this machine is shown in fig. 5. It has a circular plate of glass, which turns on an axis supported by two wooden uprights. On each side of the plate, at the upper and lower parts of the uprights, are two cushions, which act as rubbers when the plate is turned. In front of the plate are two metallic conductors supported on glass legs, and terminating in branches, which are bent round the plate at the middle of its height, and are studded with points projecting towards it. The plate becomes charged with positive electricity by friction against the cushions, and gives off its electricity through the points to the two conductors, or, what amounts to the same thing, the conductors give off negative electricity through the points to the positively electrified plate. In order to avoid loss of electricity from that portion of the plate which is passing from the cushions to the points, sector-shaped pieces of oiled skin are placed so as to cover it on both sides. The cushions become negatively electrified by the friction, and the machine will not continue working unless this negative electricity is allowed to escape. The cushions are accordingly connected with the earth by means of metal plates let into their supports.

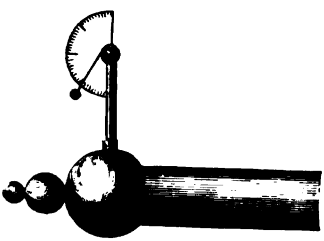


Fig. 6.

As the conductors become more highly charged, they lose electricity to the air more rapidly, and a time soon arrives when they lose electricity as fast as they receive it from the plate. After this, if the machine continues to be working uniformly, their charge remains nearly constant. This limiting amount of charge depends very much upon the condition of the air; and in damp weather the machine often refuses to work unless special means are employed to keep it dry.

The rubbers are covered with a metallic preparation, of which several different kinds are employed. Sometimes it is the compound called *aurum musivum* (bisulphide of tin), but more frequently an amalgam. Kienmeir's amalgam consists of one part of zinc, one of tin and two of mercury. The amalgam is mixed with grease to make it adhere to the leather or silk which forms the face of the cushion.

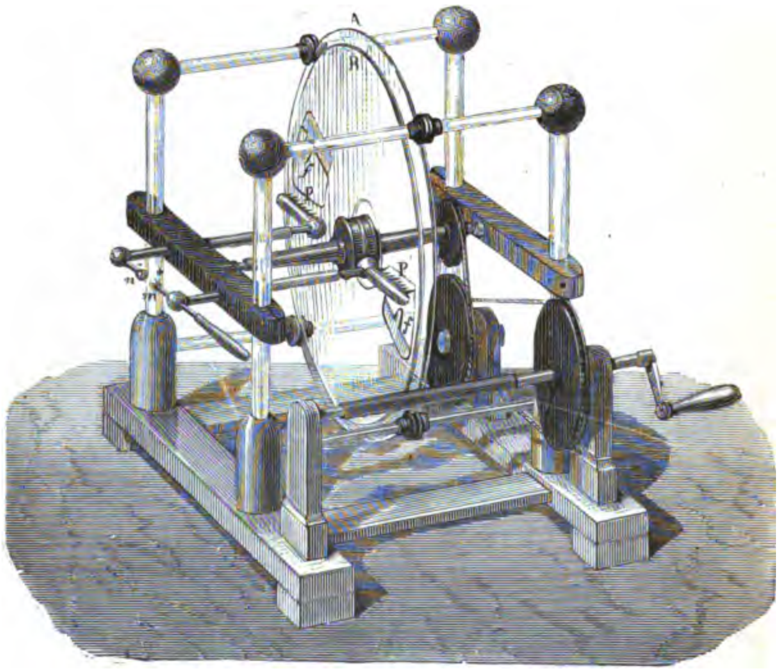


Fig. 7.

Before using the machine the glass legs which support the conductors should be wiped with a warm dry cloth. The plate must also be cleaned from any dust or portions of amalgam which may adhere to it, and, lastly, dried with a hot cloth or paper.

The variations of charge are indicated by the *quadrant electroscope* (fig. 6), which is attached to one of the conductors. It

consists of an upright conducting stem supporting a quadrant, or more commonly a semicircle of ivory, at whose centre a light needle of ivory is jointed, carrying a pith ball at its end. When there is no charge in the conductor this pendulum hangs vertically, and as the charge increases it is repelled further and further from the stem. In damp weather it will be observed to return to the vertical position almost immediately on ceasing to turn the machine, while in very favorable circumstances it gives a sensible indication of charge after two or three minutes.

In the above described machine electricity is produced by the friction of one substance against another. In the machine shown in fig. 7 a body is electrified, and then made to act by induction upon a movable system, so as to produce a continual generation of electricity.

It contains two thin circular plates of glass, one of which, A, is fixed, while the other, B, which is rather smaller, can be made to revolve very near it. In the fixed plate there are two large holes or windows near the extremities of its horizontal diameter. Across these, and partly covering them, are glued two paper bands or armatures, having points, *f f′*, directed the opposite way to that in which the movement takes place. Two metallic combs, P P′, are placed opposite the windows on the other side of the revolving plate, and are connected with two insulated conductors terminating in the knobs *n m*, which may be called the poles or electrodes of the machine. These knobs can be set at any distance asunder. In starting the machine they are placed in contact, and one of the armatures—suppose *f*—is electrified by holding against it a sheet of vulcanite which has been charged with negative electricity by friction. The plate is then turned for a few seconds, and the two knobs are gradually separated.

A continuous crackling noise is immediately produced at the place of separation, resulting from electric discharge across the interval. In the circumstances supposed the knob *n* is the negative, and the knob *m* the positive electrode. In dry weather the machine, when once started, will continue in action for a

long time if the motion is kept up, but it soon ceases to act if the air is damp, being even more sensitive to moisture than the ordinary machine.

The action of the machine is as follows: The negative electricity of the armature *f*, acting inductively on the opposed conductor, from which it is separated by the revolving plate, causes this conductor to discharge positive electricity through the comb upon the face of the plate, and thus to acquire a negative charge. When the part of the plate which has been thus affected comes opposite the other armature the latter is affected inductively, and discharges negative electricity through its point *f′* upon the back of the plate, thus becoming itself positively electrified. Positive electricity from the front of the plate is, at the same time, collected by the comb P′, an equal quantity of negative being of course discharged from the comb upon the plate. In the subsequent stages of the process the negative electricity thus discharged upon the face of the plate exceeds the positive which was previously there, so that the face of the plate passes on with a negative charge. When the portion of the plate which we are considering again comes opposite *f* it increases the negative electrification both of the armature and the conductor, inasmuch as it has more of negative or less of positive electricity upon both its surfaces than it had when it last moved away from that position. Both armatures thus become more and more strongly electrified, until a limit is attained which depends on the goodness of the insulation; and as the electrification of the armature increases the conductors also become more powerfully affected, and are able to discharge to each other by the knobs *m n* at a continually increasing distance.

THE ELECTROPHORUS.

When electricity is required in comparatively small quantities, it is readily supplied by the simple apparatus called the electrophorus.

This consists (fig. 8) of a disc of resin, or some other

material easily excited by friction, and of a polished metal disc B, with an insulating handle C D. The resin disc is electrified by striking or rubbing it with catskin or flannel, and the metal plate is then laid upon it. In these circumstances the upper plate does not receive a direct charge from the lower, but, if touched with the finger (to connect it with the earth), receives an opposite charge by induction. On lifting it away by its insulating handle it is found to be charged, and will give a spark. It may then be replaced on the lower plate (touching it at the same time with the finger), and if the weather is favorable, the process may be repeated an indefinite number of times without any fresh excitation.

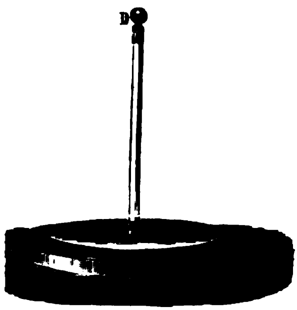


Fig. 8.

The resinous plate has usually a base of metal, which is in connection with the earth while the electrophorus is being worked. This base, by the mutual induction which takes place between it and the upper plate, increases the capacity of the latter, and thus increases the charge acquired. When the cover receives its positive charge on being connected with the earth, the base at the same time receives from the earth a negative charge, and as the cover is gradually lifted this negative charge gradually returns to the earth.

The most convenient form of the electrophorus is that in which the cover, when placed upon the resinous plate, comes into metallic connection with the metal plate below. That this arrangement is allowable is evident, when we reflect that, when the upper plate is touched with the finger, it is in fact connected with the lower plate, since both are connected with the earth; and it effects a great saving of time when many sparks are required in quick succession, for the cover may be raised and lowered as fast as we please, coming alternately into contact with the resinous plate and the body which we wish to charge.

THE ELECTRICAL DOUBLER.

The purpose of the Electrical Doubler is to increase the least conceivable quantity of electricity by continually doubling it, until it becomes perceptible upon a common electrometer or made visible in sparks.

The principle involved in the construction of the Doubler will be best understood by explaining the first device of this kind, invented by Mr. Bennet. This apparatus consisted of a circular brass plate three or four inches in diameter, polished and thinly varnished on the upper surface, upon which was placed another brass plate of equal diameter, polished and varnished on both sides, with an insulated handle attached to one edge of it. A third plate was also provided, of equal diameter, polished and varnished on the under side, and with a perpendicular insulating handle extending from the centre of the upper side. Its mode of operation is as follows:

Electricity is communicated to the under side of the first plate and the second plate is touched with the finger. The second plate is then removed from the first by its insulating handle and the third plate is placed upon the second. The third plate is then touched by the finger and then separated from the second. In this situation it will be apparent that two of the plates are charged with one kind of electricity, and of nearly equal quantity, and one of the plates with the other kind of electricity. The third plate is now touched to the under surface of the first plate, the first plate being covered by the second, and the second plate is touched by the finger. If now the third plate is removed, and the finger withdrawn from the second plate, and the latter is lifted up from the first plate, the electricity becomes doubled. This process may be repeated ten or twenty times, and by doubling the quantity of electricity every

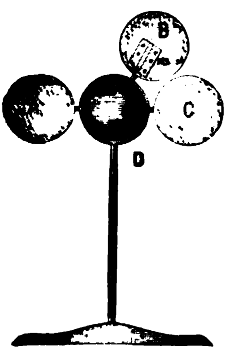


Fig. 9.

time, the smallest conceivable amount can be made visible, since at the twentieth operation it is increased 500,000 times.

In order to avoid the labor of the preceding operation Dr. Darwin invented the movable doubler, consisting of four metallic plates moved by wheel works, but requiring to be touched by the hand in order to produce the effect. This apparatus has been superseded by Nicholson's Revolving Doubler, which is represented by figures 9 and 10. The instrument is supported on a glass pillar 6½ inches long, and consists of two fixed plates of brass, A C, two inches in diameter, separately insulated and placed in the same plane, so that a revolving plate, B, may pass near them without touching. A brass ball, D, two inches in diameter, is fixed on the end of the axis that carries the plate B, and is loaded within at one side to act as a counterpoise to the revolving plate B, so as to keep it at rest in any position. The axis, P O, is made of varnished glass, and so are those that join the three plates with the brass piece M, which supports the plates A and C. At one extremity of this axis is the ball D, and the other is connected with a rod of glass, N O, upon which the handle L is fixed, and also the piece G H, separately insulated. The pins E F rise out of the back of the fixed plates A C at unequal distances from the axis. The piece K is parallel to G H, and both of them have their ends armed with small pieces of steel wire that they may touch the pins E F in certain points of their revolution. In the piece M there is fixed a pin, I, which intercepts a small wire proceeding from the revolving plate B. These wires are so adjusted by bending that when the plate B is exactly opposite to A the piece G H

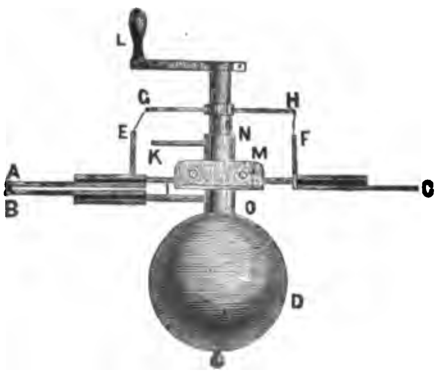


Fig. 10.

connects the two fixed plates, while the wire and pin at I form a connection between the ball D and the plate B. On the contrary, when the plate B is exactly opposite to the plate C the ball D becomes connected with C by the contact of F with the wire at K, the plates A and B being then completely unconnected with any part of the apparatus. In all other positions the three plates and the ball will be perfectly unconnected with each other.

ELECTROSCOPES.

Instruments employed to detect the presence of electricity are called electroscopes, while such as are employed to measure its quantity are called electrometers. This distinction, however, is frequently neglected, and instruments of either kind are called electrometers.

The gold leaf electroscope is the most convenient instrument for testing electricity of feeble tension. It consists of two narrow slips of gold leaf suspended by a metallic rod in a glass cylinder. The slips of gold leaf are thus insulated and protected from the influence of currents of air, and electricity may be communicated to them by bringing an electrified body in contact with the top of the metallic rod. In their natural state the two slips hang in contact, but when electricity is imparted to the rod the leaves diverge from each other. To ascertain the kind of electricity with which a body is charged, an electrified glass tube is brought near the top of the rod, causing the leaves to diverge by induction, and when so diverging the rod is touched with the finger, and the leaves fall. In this state — electricity is fixed by the action of the + electricity of the tube on the side of the rod next it, and the corresponding + electricity goes to the earth. When the finger is removed the + electricity is cut off, while the — electricity remains on the top of the rod, and its presence is manifested by the leaves diverging permanently after the removal of the tube. If a positively electrified body is now brought near the rod it will draw away the — electricity from the leaves, and they consequently fall, but if

a negatively electrified body be brought near it will send the — electricity into the leaves and they will diverge further.

ELECTROMETERS.

Coulomb's electrometer is an apparatus still more delicate for detecting electricity and measuring its quantity. It consists of a cylindrical glass vessel A A (fig. 11), from the upper end, B, of which rises another glass cylinder D D of much smaller diameter. This small cylinder is fitted at the top with a brass cap *a*, carrying an index C. Outside of this, and capable of turning round it, is another cap *b*, the top of which is divided into 360 equal parts. In the centre of the cap *b* is an opening through which a small metal cylinder *d*, capable of turning in the opening with moderate friction, and having at its lower end a notch or slit. When the cap *b* is turned, the cylinder *d* turns with it; but the latter can also be turned separately, so as not to change the reading. These parts compose the torsion-head. A very fine metallic wire is held by the notch, and supports a small piece of metal, through which passes a light needle of shellac *f*, carrying at one end a small gilt ball *g*. A circular scale runs round the outside of the large cylinder in the plane of the needle. Finally, opposite the zero of this scale, there is a fixed ball *g'* of some conducting material, supported by a rod *f*, of shellac, which passes through a hole in the cover of the cylindrical case.

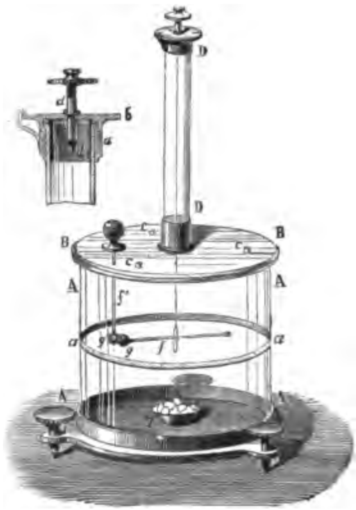


Fig. 11.

When the instrument is adjusted for observation the index is set to the zero of the scale. The inner cylinder *d* is then turned until the movable ball just touches the fixed ball without any

torsion of the wire. The fixed ball is then taken out, placed in communication with an electrified body, and replaced in the apparatus.

The electricity with which it is charged is communicated to the movable ball, and causes the repulsion of this latter through a number of degrees indicated by the scale which surrounds the case. In this position the force of repulsion is in equilibrium with the force of torsion tending to bring back the ball to its original position. The graduated cap *b* is then turned so as to oppose the repulsion. The movable ball is thus brought nearer to the fixed ball, and at the same time the amount of torsion in the wire is increased. By repeating this process we obtain a number of different positions in which repulsion is balanced by torsion. But we know, from the laws of elasticity, that the force of torsion is proportional to the angle of torsion. Hence, we have only to compare the total amounts of torsion with the distances of the two balls. By such comparisons Coulomb found that the force of electrical repulsion varies *inversely as the square of the distance.*

When an electrified ball is placed in contact with a precisely equal and similar ball, the charge will be divided equally between them, so that the first will retain only half the charge which it had before contact.

Suppose that an observation on repulsion had just been made with the torsion-balance, and that we touch the fixed ball with another exactly equal insulated ball, which we then remove, it will be found that the amount of torsion requisite for keeping the movable ball in its observed position is just half what it was before. The same result will be obtained by touching the movable ball with a ball of its own size. We conclude that, if the charge of either body be altered, the attractive or repulsive force between the bodies at a given distance will be altered in the same ratio. The law is not rigorously true for bodies of finite size, unless the distribution of the electricity on the two bodies remains unchanged.

CHAPTER IV.

DISTRIBUTION OF ELECTRICITY.

EXPERIMENT shows us that static or frictional electricity is exhibited only on the surfaces of conductors. This is illustrated by the apparatus represented in fig. 12.

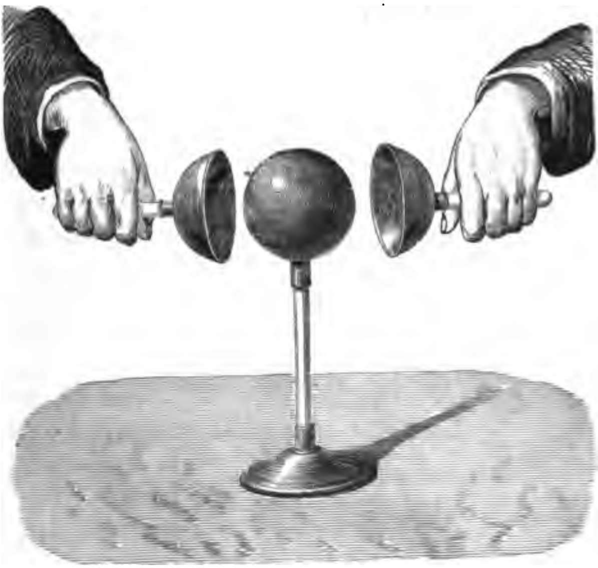


Fig. 12.

An electrified metallic body is supported by a glass rod which insulates it from the earth, and is then covered with two hemispheres, furnished with insulating handles, which fit the sphere exactly. If the two hemispheres be quickly removed, and presented to an electroscope, they will be found to be electrified, while the sphere itself will show hardly any traces of electricity.

If we electrify a hollow sphere the electricity will pass immediately to the surface, and there will be no trace of electricity on the interior. This is proven by the introduction of a proof-plane into the interior of a highly electrified ball (fig. 13), upon the withdrawal of which no perceptible charge of electricity can be detected.

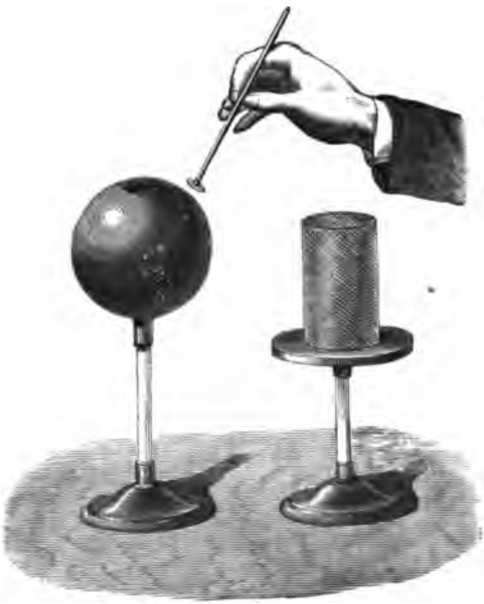


Fig. 13.

Faraday varied this experiment by substituting a cylinder or wire gauze for the sphere. This cylinder rested on an insulated disc of metal. The disc was charged with electricity, and it was found that no trace of the electricity could be detected by applying the proof-plane to the interior surface of the cylinder.

The distribution of electricity on a sphere is unaffected by the mass of the body, provided the surface remain constant. Spheres made of wholly different materials, but of the same size, if their surfaces be conductors, will abstract precisely the same quantity of electricity from any electrified body with which they may be brought in contact.

The power which is exerted by one electrified body on another similar body, other things being the same, depends on the quantity of electricity which it holds.

If one insulated metallic ball be negatively electrified, and another exactly similar be positively electrified, they will, upon

being brought in contact, assume the same electrical condition. If the positively electrified ball contained the most electricity, both balls will be positively electrified. If the negatively electrified ball contained the most, both balls will be negatively electrified. In both cases the quantity of electricity on the two balls, after contact, will be equal to the difference of the charge on the two balls at first.

The greater the surface over which electricity is diffused the less is its power at any particular point. When two equal balls are insulated and a charge is given to one of them, and then communicated to the other by contact with the first, it is found that both equally divide the charge; but that the quantity of the electricity of each is one half of that of the originally charged ball.

When the proof-plane is applied to different parts of the surface of a conductor the quantities of electricity which it carries off are not usually equal. But the electricity carried off by the proof-plane is simply the electricity which resided on the part of surface covered by it, for the proof-plane, during the time of its contact, is virtually part of the surface of the conductor. We must, therefore, conclude that equal areas on different parts of the surface of a conductor have not equal amounts of electricity upon them. It is also found that if the charge of the conductor be varied, the electricity resident upon any specified portion of the surface is changed in the same ratio. The ratio of the quantities of electricity on two specified portions of the surface is in fact independent of the charge, and depends only on the form of the conductor. This is expressed by saying that *distribution* is independent of charge, and that the distribution of electricity on the surface of a conductor depends on its form. Electricity tends to accumulate on all projections, and the density at points is necessarily large.

ELECTRIC DENSITY.

The term "electric density" signifies the quantity of electricity per unit area on a charged conductor. The name is appro-

priate from the analogy of ordinary material density, which is mass per unit volume, and is not intended to imply any hypothesis as to the nature of electricity.

The dotted line in each of the following figures is intended to represent by its distance from the outline of the conductor the electric density at each point of the latter.

Fig. 14.

If the electrified body be a sphere (fig 14), the electricity will be distributed uniformly over the surface.

If the electrified body be an ellipsoid (fig. 15), the density is greatest at the ends of the longest, and least at the ends of the shortest axis, and the densities at these points are simply proportional to the axes themselves. More generally, however, the density at any point on the surface of an ellipsoid is proportional to the length of a perpendicular from the centre of the ellipsoid on a tangent plane at the point. If an ellipsoid, similar and nearly equal to the given one, be placed so that the corresponding axes of the two are coincident, we shall have a thin ellipsoidal shell, whose thickness at any point exactly represents the electric density at that point. Such a shell, if composed of homogeneous matter attracting inversely as the square of the distance, would exercise no force at points in its interior.

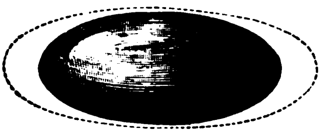


Fig. 15.

If the ellipsoid be very elongated the density of the fluid at the ends will be proportionately great. If the electrified body be drawn out to a point the density of the electricity at that point will be exceedingly great, and the electricity will escape rapidly through the air.

On the flat disc (fig. 16), the density is almost inappreciable over the whole of both faces, except close to the edges, where it increases almost by a jump.

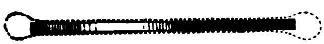


Fig. 16.

On the cylinder with hemispherical ends (fig. 17), the density

is a minimum, and nearly uniform at parts remote from the ends, and attains a maximum at the ends. The ratio of the density at the ends to that at the sides increases as the radius of the cylinder diminishes, the length of the cylinder remaining the same.

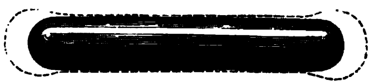


Fig. 17.

In the case of equal spheres in contact, the charge, which is nothing at the point of contact, and very feeble up to 30° from that point, increases very rapidly from 30° to 60°, less rapidly from 60° to 90°, and almost insensibly from 90° to 180°. When the spheres are of unequal size, the charge at any point on the smaller sphere is greater than at the corresponding point on the larger one; and as the smaller sphere is continually diminished, the other remaining the same, the ratio of the densities at the extremities of the line of centres tends to become as two to one.

The distribution of electricity on a conductor of any form may be described by saying that the density is greatest on those parts of the surface which project most, or which have the sharpest convexity, and that in depressions or concavities it is small or altogether insensible. Theory shows that at a perfectly sharp edge, such, for example, as is formed by two planes meeting at any angle, however obtuse, but not rounded off, the density must be infinite, and with greater reason it must be infinite at a perfectly sharp point, for example, at the apex of a cone, however obtuse, if not rounded off. Practically, the points and edges of bodies are always rounded off; the microscope shows them merely as places of very sharp convexity (that is, of very small radius of curvature), and hence the electric density at those places is really finite; but it is exceedingly great in comparison with the density at other parts, and this is especially true of very acute points, such as the point of a fine needle. The consequence is, that if a pointed conductor is insulated and charged, the concentration of a large amount of repulsive force within an exceedingly small area produces very rapid escape of electricity at the points. Conductors intended to retain a charge of electricity must have no points or edges, and must be very smooth. If of considerable length in proportion to their breadth, they are usually made to terminate in large knobs.

CHAPTER V.

BOUND ELECTRICITY.

THE Condenser is an apparatus by means of which a large quantity of electricity can be gathered on a small surface. Its form may be greatly varied, but the essential parts consist of two good conductors, which are separated from each other at a small distance by a non-conductor.

For the conductors there are ordinarily taken two metallic plates, A B C D (fig. 18), between which, as a non-conductor, there is a stratum of air, or still better, a glass, caoutchouc or gutta-percha plate E F. When one of the metallic plates A B is connected with an electric body R, such for example as the positive conductor of an electrical machine, or some other source of electricity, and the other plate, C D, by means of a wire with the ground, then the + of R is communicated to the plate A B. If the plate C D were not there, the quantity of electricity on A B would depend on the amount of surface of A B, and the tension of the prime conductor R. But the presence of the plate C D alters the case most essentially. In the first place the electricity of A B cannot communicate with plate C D, owing to the inter position of the non-conductor E F. Consequently, the electric influence enters in exactly as in the case of static induction described in Chapter II. The + E of plate A B analyzes in

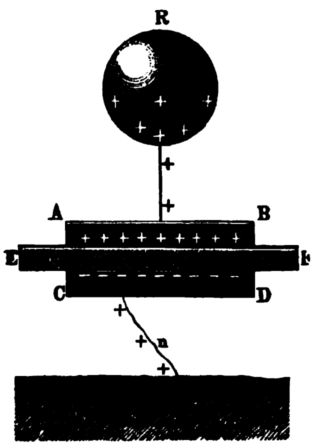


Fig. 18.

the first place the plate beneath, attracts the — E, and repels the + E through *n* into the earth. But at the same time the — E of the plate C D is *bound* by the + E of plate A B; and the + E of the upper plate is also bound by the — E of the under plate.

Plate A B being at some distance from plate C D, the entire quantity of + E, which is present at A B, cannot bind an equal quantity of — E. The nearer both plates are brought towards each other the more — E can be bound by the + E of plate A B. For the same reason the bound — E of the under plate C D cannot bind an equal portion of + E of the upper plate, so that of the + E on plate A B only a part is bound, and the other part is free. The bound + E on A B being so situated as if it were not present at all at A B, is therefore called *latent* electricity, and thus it is only the smaller part of the free electricity of this plate which determines the electric tension. This tension, after the first passage of the + E from R to A B, is far less than it is at R, and thus a fresh quantity of + E can pass to A B. However, almost the same thing occurs now that happened at the passing over of the first quantity of electricity from R to A B, namely, as at the very beginning the + E passed through *n* into earth, it becomes neutralized with an equal quantity of — E from the ground, so that immediately after the first influence the conducting wire *n*, as well as the plate C D and the bound — E, could supply the latter with fresh + E.

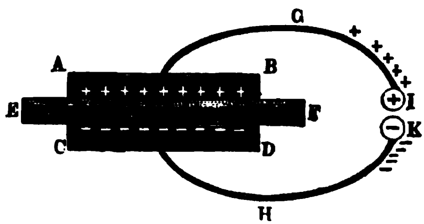


Fig. 19.

This + E becomes analyzed by the second + E passing from R to A B; the — E of the under plate again becomes bound, and in return binds a part of the + E flowing from R, by which again a part of the latter remains free, and the electric tension on A B increases.

This process is constantly repeated until the tension at A B

is the same as at R; when this is obtained, no electricity can pass from R to A B; at that time at A B a large quantity, comparatively speaking, of + E has gathered, and on C D likewise a corresponding but smaller quantity of — E; of the former the greater part is bound by the — E of the plate C D, and even the latter is constantly bound by the + E of the plate A B. When this condition is entered upon, the condenser is charged.

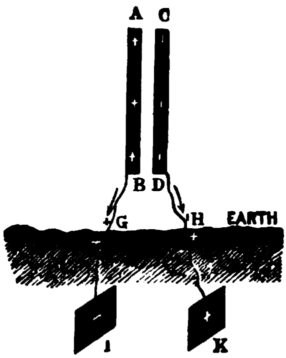


Fig. 20.

When the connection with R and the earth is broken, there is present at A B free + E and bound + E, the latter evidently in a state of heavy condensation, while the under plate contains bound and condensed — E. Both bound electricities are attracted in an opposite way towards both surfaces of the non-conductor E F, and this attraction is so strong that the electricities penetrate to a certain depth in the non-conductor E F.

When the source of electricity R is able to constantly supply an infinite or exceedingly large quantity of electricity, its electric tension in charging the condenser does not decrease, and this charging takes place almost immediately. When this is not the case, and the electricity is only produced by degrees at R, as in the electrical machine, the condenser also only becomes charged by degrees, the rapidity of the charge depending upon the rapidity of the development of the electricity on R.

When the charge has taken place, plate C D can be touched with the hand without changing the condition of the charge, the — E of this plate being constantly bound, and consequently not able to be diverted. However, when the upper plate A B is touched, the free + E of this plate is led off to earth. The — E of the *under* plate (to whose binding as well as the bound and free + E of the upper plate is required) is retained only by the bound + E of the plate A B, and, consequently, cannot be

kept constantly bound any longer; a part of this — E thus becomes free, and the rest remains bound. At present all the + E on A B is bound, while, on the contrary, the — E on C D is partly bound and partly free. Now, if the under plate is again touched, the free — E is renewed, which again sets free a part of the + E on A B, and again binds all — E on C D. Touch A B again, the + E, which becomes free last of all, is diverted, by which, again, a part of the — E at C D becomes free.

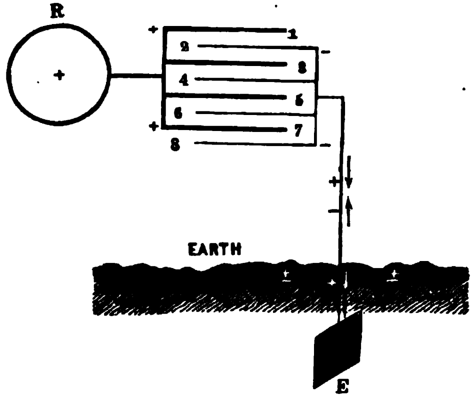


Fig. 21.

If we continue in this way to connect plate A B and C D alternately with the earth, the condenser will become discharged by degrees. On the contrary, if the condenser, after having been charged, has its connection with the source of electricity and the ground broken, and its two conductors G and H (fig. 19) connected with the plates A B and C D, and the extreme ends of these conductors are brought near to each other, a portion of the free + E will pass from A B to G; and as all the — E can no longer remain bound on C D, a part thereof becomes free and proceeds to H. The result of this is that the primitive quantity of the + E can no longer remain bound on A B, and a part of the + E which was bound heretofore becomes free at A B and passes to G, and, as a consequence hereof, again a part of the — E, at C D, becomes free, and passes to H, and hence free + E is accumulated at G I and free — E at H K. The charge of the condenser plates decreases somewhat in consequence hereof, and the nearer the extreme ends I and K approach each other, the stronger the tension of

the opposite electricities at I and K becomes. When this tension has become considerable enough, in consequence of a nearer approach of I and K to overcome the resistance of the stratum of air, located between them, then both electricities become combined, and an electric spark is seen between I and K. Both electricities which were gathered at A B and C D now unite through G and H with almost inconceivable rapidity, so that between I and K only a single spark occurs, and the condenser is discharged at once.

If, instead of both conductors G and H, we take only one conductor, for instance, G, and bring its extreme end, I, near the plate C D, we obtain almost identically the same result. The same occurs when both plates A B and C D are connected by wires with the earth. In this case a portion of the free + E of plate A B (fig. 20) passes through G to the earth I, and analyzes there the $\pm$ E of the earth, and equalizes with the — E. By this process a corresponding part of the — E of the plate C D becomes free, and passes over H to K, and there recombines with the + E of the earth. In this manner, as we have explained heretofore, both electricities, + E and — E of the plates go to earth, and the condenser is discharged. In this case it is usual to say that the electricities of the condenser flow to earth, or the earth, acting as a very large reservoir, takes up or absorbs both electricities, but we ought instead to look upon the discharging not as a disappearing of the electricities from the condenser into the earth, but as an equalization of its electricities with the opposite electricities of the earth. After the discharge, both plates A B, C D are not entirely devoid of electricity, as would be the case with a reservoir, when the latter had poured out its contents, but each plate is again saturated with a quantity of + E adequate to the size of its surface. Upon a closer inquiry we find that the electricities are not gathered on the metallic plates A B and C D, but on both surfaces of the insulator E F, which are in contact with the metallic plates. When the condenser is charged, if plate C D, fig. 18, is removed by means of an isolating handle, and the plate

is examined, it will appear to be completely non-electrical; on the contrary, plate A B shows a small quantity of free electricity; if now these plates are separately touched and then again put together, as in fig. 18, the condenser is found to be completely charged, and when discharged produces a spark.

The electricities, however, not only adhere to the surface of the non-conductor E F, but they even penetrate, on account of their opposite attraction, to a certain depth into the surface of the non-conductor, and, when the non-conductor is very thin they may unite again in its interior, and in this manner cause a discharge. This is the reason why the condenser, in discharging by means of both conductors G and H (fig. 19), does not at once become completely discharged, but, after the first spark appearing between I and K, still remains slightly charged, and does not become discharged until I and K are again and again brought into contact.

The greatness of the charge of a condenser depends on the size of the surfaces of the non-conductor with which the condenser plates are in contact, on the tension of the electricity in the body which furnishes the charge, and on the distance of the metallic plates, or the dimension of the non-conductor which is situated between them. If the electric tension in the body which produces the charge is small, then the metallic plates ought to be brought very near to each other; in such a case the metallic plates are merely separated by a thin stratum of shellac, wherewith the surfaces of these plates, turned towards each other in juxtaposition, are covered.

The form of the condenser varies according to the end proposed with it. When a great deal of electricity is to be gathered with it, and the source of electricity is not large, not only the condensing metallic surfaces must be very extended, but they should be placed very close to each other, without, however, coming in contact at any point. Sheets of thin glass or thin plates of mica or gutta-percha, covered on both sides within a short distance from the edge with tin foil, are in many cases adapted to this end. When, however, the surface of the con-

denser is required to be so large that these contrivances will not suffice, leaves of thin paper saturated with paraffin, and covered on both sides with tin foil, must be used.

The leaves are then laid singly one upon another, like the pages of a book, and the tin foil plates are connected together in two series, upper and under, each by themselves. In this manner two separate rows of metallic plates are formed, which stand very close to each other, but are separated by the non-conducting paraffin paper, and thus represent a large surface without taking up much room.

In the condenser shown in fig. 21 the uneven numbers, 1, 3, 5, 7, indicate the four upper; the four even numbers, 2, 4, 6, 8, the four under tin foil coatings of four paraffin leaves. When one of the rows, for instance that of the upper tin foil leaves, is connected with a source R of + E, and that of the under tin foil leaves with the ground E, the condenser becomes charged in the manner above described; the upper tin foil leaves condense the + E; the under ones, the — E, and the collective quantity of electricity gathering in the condenser may become very considerable, even with a feeble source of electricity R, if the latter flows a short time, provided a sufficiently large number of leaves are employed.

THE LEYDEN JAR AND THE ELECTRIC BATTERY.

In the Leyden Jar we have a condenser of a different form, which is used to maintain the opposing electricities in a state of the greatest possible tension, and having the strongest tendency to unite with each other and reëstablish the equilibrium. It consists of a glass jar or bottle coated both on its inner and outer surfaces with tin foil, the coatings however terminating some distance below the neck, as shown in fig. 22. An upright brass rod, terminating in a knob, is connected with the inner coating. Such a jar may be charged in the same way as a condenser, the outer coating being in connection with the earth, and the inner one with the prime conductor of an electrical machine. The + E is accumulated upon one coating, for ex-

ample, the inner one, and the — E upon the other, or outer one. The greater the accumulation of electricity upon the opposite coatings, the more powerful becomes their tendency to unite. To reëstablish the equilibrium it is only necessary to form a connection between the two coatings by a conductor, for instance, a metallic wire, or even the human body. The union of the opposing electricities, or as it is termed, the discharge of the jar, follows with a bright spark and a sharp report, and when passed through the human body causes a shock of more or less intensity in the joints of the arms.

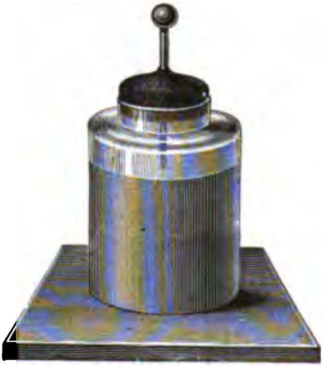


Fig. 22.

In order to obtain a high degree of tension several jars are connected together, forming an *electrical battery* (fig. 23), the outer coatings of the several jars being all connected together, and the inner ones in the same manner. This is accomplished by placing all the jars upon a surface of tin foil, and by connecting the vertical brass rods projecting from each jar by means of horizontal wires.

Fig. 23.

When such a battery has been charged in the same manner as a single jar, and a conducting connnection is formed between the inner and outer coatings, the accumulated electricities unite with great force; the spark is more vivid, and the report is louder.

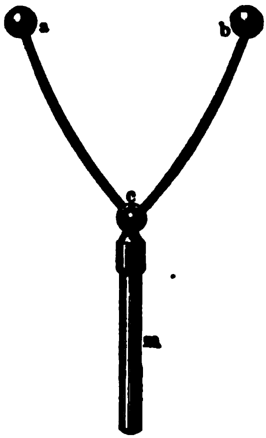


Fig. 24.

The connection is usually effected by means of a pair of curved brass rods jointed at *c* (fig. 24), and provided with brass knobs *a b*, and an insulating handle *m*. The jar is discharged by simultaneously touching one knob to the outer coating and the other to the knob of the jar, when the discharge instantly follows. This arrangement is termed a "discharger."

The amount of electricity which a jar can receive, provided it be of uniform thickness, is proportional to the coated surface, and inversely proportional to the thickness of the glass.

CHAPTER VI.

VOLTAIC ELECTRICITY.

VOLTAIC Electricity is the branch of the science of electricity which treats of the electric currents arising from chemical action, more particularly from that attending the dissolution of metals. It is sometimes called dynamical electricity, because it deals with current electricity, or electricity in motion, and is thus distinguished from frictional electricity, which is called statical, in consequence of its investigating the electrical condition of bodies in which electricity remains insulated or stationary. These terms, although in the main thus properly applied, are in all strictness applicable to both sciences. Frictional electricity, though small in quantity, can pass in a sensible current, and galvanic electricity, though small in tension, can be made to manifest the attractions and repulsions of statical electricity. Thus the series of discharges which are transmitted in a wire connecting the prime conductor of a machine in action with the ground or negative conductor, possesses, though feebly, the characteristics of a galvanic current; and the insulated poles of a many-celled galvanic battery manifest, before the current begins, the electric tension of the friction machine.

The observations made in 1789, by Galvani, that the legs of a prepared frog are convulsed when their muscles are connected with a strip of copper, their nerves with a strip of zinc, and the opposite end of the two strips are united, convinced Volta, after a great deal of experimental investigation, that these phenomena were due to electrical action. The result of Volta's researches established the fact that when two dissimilar metals come into contact they become electric, and the force of the electrical commotion depends upon the nature of the metals. This force acting on the point of contact of dissimilar metals, is called elec-

tromotive force. It divides the electricities present in the natural condition of the metals, and forces from the point of contact the + fluid in one of the bodies, and the — fluid in the other, where they remain in a state of rest and tension, in an effort to unite again, until finally they find some means of coalition and equalization. All the metals as well as the carbons are good electromoters, but no two metals develop in connection with any other the same degree of electrical tension. Zinc, for instance, in contact with platinum, becomes more electric than when in contact with copper; and copper in contact with platinum becomes + electric, while in contact with zinc it becomes — electric. The following series of bodies is so arranged that any of them in contact with some other becomes electric, and each preceding body in this series in contact with the succeeding body is + electric, while the succeeding body is — electric: + zinc, lead, tin, iron, copper, silver, gold, platinum, carbon —.

GALVANIC CURRENT

When in Fig. 25 the zinc plate *a b* comes in contact with the copper plate *a c*, the + E of both metals gather on the zinc plate, and — E on the copper plate.

Both electricities are in a state of tension or of desire to unite again, which, however, they are not able to do, owing to the

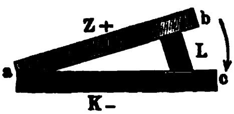


Fig. 25.

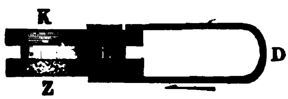


Fig. 26.

inability of the source of commotion (the contact place *a*) to take the lead. Now, if we connect the zinc and the copper plate by a moist conductor L, for example, by a strip of pasteboard soaked in water, or in diluted sulphuric acid, or if we dip both contiguous plates in such a fluid, the union of both separated electricities takes place through this moist conductor, the + E flows from the zinc through the conductor in the direction of the arrow towards the — E of the copper, the — E of the cop-

per on the contrary in the opposite direction towards the + E of the zinc, and the electric flow would at once cease were it not that in the continuing contact of the metals a source of an ever new analysis of electricity were to be found. At the same moment that both electricities pass through the moist conductor and become equalized, the electromotive force produces at the point of contact *a* a new electric analysis, which likewise, however, becomes at once equalized again, to make room for a new tension.

In this apparatus, which is styled an open voltaic or galvanic circuit as long as there is no moist conductor, and a closed voltaic or galvanic circuit or a single galvanic element as soon as the moist conductor is put in, a continuous flow of both opposite electricities takes place in opposite directions. The flow of the + E proceeds from the zinc through the fluid to the copper; outside of the fluid it passes from the copper over the contact point to the zinc. This uninterrupted equalization of both electricities forms a continuous flow, which is styled a *galvanic current*. When we speak of the direction of a galvanic current, we always mean the direction of the + electricity in motion for the time being, which follows outside of the fluid from the copper to the zinc.

In order to become convinced of the presence of a specific electrical action when two different metals come in contact, we may place a strip of zinc under the tongue, a piece of silver or copper on the tongue, and then put both pieces outside of the tongue in contact, and we shall instantly perceive a peculiar taste, which we have not discovered previous to the metals coming in contact; or we may put the strip of zinc under the lower eyelid, this being previously somewhat moistened, and squeeze the strips of copper between the upper lip and the gums, and at the moment when both metals are brought into contact we shall perceive a weak ray of light before our eyes.

The most simple form of a closed voltaic circuit is represented in Fig 26, in which Z is the zinc plate, K the copper plate, L the moist conductor, and D a copper wire connecting Z and K, styled the closing wire.

When we replace the moist disk by a fluid, the element takes the form of Fig. 27, where Z k represents the plate of zinc, and C u the copper. The galvanic current, or the motion of the + E, follows in both cases in the direction of the arrow, to wit, outside of the fluid from copper to zinc.

GALVANIC BATTERIES.

If, as is represented in Fig 28, several compound pairs of zinc and copper plates are put up in layers, always in the same order,

Fig. 27.

Fig. 28.

and between each pair a moist conductor is inserted, such as a disk of felt, cloth or pasteboard, so that the succession of the bodies arranged on each other from top to bottom is as follows:

Copper, zinc, conductor | copper, zinc, conductor

Copper, zinc, conductor | copper, zinc; one end of the series terminating with zinc, and the other end beginning with

copper, a current will flow when both ends are connected by a wire, and the more pairs of plates the series contain the greater will be its electromotive force. The extreme ends of the series are called poles. The pasteboard disks are soaked in water, mixed with common salt or sulphuric acid, and thus allow an easier passage to the current than when they are moistened with pure water.

When a fluid is used instead of a moist disk, the battery has the form represented in Fig. 29. In each glass is a zinc and a

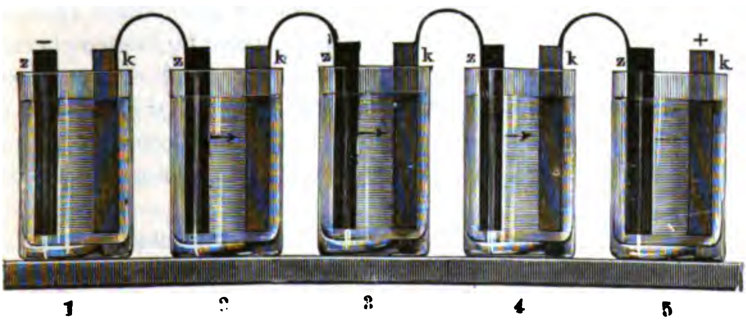


Fig. 29.

copper plate, and each zinc plate of one of the vessels is connected by a copper wire with the copper plate of the preceding vessel. The poles of the battery indicated by + and — are both connected with closing wires. As is represented in the drawing by arrows, inside the cells the positive current passes from zinc to copper—and externally, that is to say, in the closing wire, from copper to zinc.

As electricity is also created through the contact of a metal with a fluid, the action of a voltaic battery will be plainly understood when it is granted that the seat of the force which creates the electricity is not only to be found in the contact points of both metals, but in the contact between the metal and the fluid; hence some electricians have recently so enlarged upon Volta's theories in this respect as to admit, besides the creation of electricity through the contact of metals, still another similar force at the contact point of the metals and the fluids. Opposed

to these are the advocates of the chemical theory, who contend that electricity in a galvanic element is created only by a chemical action which takes place between the fluids and the metals. In truth, however, both contact between dissimilar substances and chemical action are necessary to produce voltaic electricity. The laws regulating the potential and those regulating the current are intimately connected with the nature of the substances in contact and with the amount of the chemical action. Perhaps it is strictly accurate to say that difference of potential is produced by contact, and that the current which is maintained by it is produced by chemical action. In cases where no known chemical action occurs, as where copper and zinc touch one another, the difference of potential is produced, and since this involves a redistribution of electricity, a small but definite consumption of energy must then occur. The source of this power cannot yet be said to be known.

If both poles of a galvanic battery are connected through a conducting wire, the latter shows a succession of phenomena which may conveniently be arranged in five classes, to wit: 1, The phenomena of light; 2. The production of heat; 3. Physiological effects; 4. Chemical, and 5, Magnetic effects.

The phenomena of light are perceptible even with a single galvanic element of large surface. If the extreme ends of the wires starting from the poles are brought together, as in Fig. 28, we perceive, when separated, if the ends have been previously amalgamated, a beautiful bright spark. The current which passes when the contact is made does not cease with the separation, but forces its way through the intervening air. If we take a battery of 40 or 50 elements and put carbon points on the exteme ends of the wires, there will appear between the points a splendid light, whose dazzling brilliancy blinds the eye. It is deserving of notice that, whilst frictional electricity has such an enormous tension that, under favorable circumstances, sparks will leap across the air to neighboring conductors, at a distance of 40 inches, we may place the poles of a very powerful galvanic battery to within $\frac{1}{20000}$ of an inch of each other with-

out any spark passing over or the battery sending any current. The ordinary galvanic battery is, therefore, unlike the electric machine and the Leyden jar battery in respect to tension.

The production of heat by the galvanic current is likewise apparent, even in a single element of large surface, where a fine platina wire inserted in the closing wire becomes red hot. By means of a series of these elements, or a voltaic battery, this metal is easily melted.

The physiological actions of the galvanic current are manifested even by a single element in affecting the taste and the optic nerves. They appear in a far greater degree when the terminal wires of a powerful galvanic battery are seized by moist hands, causing an almost intolerable sensation, and burning in the arms and breast. Upon this fact are founded also the highly interesting experiments which are often made with galvanic currents on recently killed animals and human beings.

The chemical actions of the galvanic current are, in their theoretical and practical relations, still more important, affording an insight into the nature and origin of the current, as well as of the construction of the galvanic elements. They are frequently used in electroplating, electrotyping and gilding, and also in telegraphy.

When, as in L, in Figs. 25, 26 and 27, a part of the conductor consists of water, its materials, oxygen and hydrogen, become analyzed by the action of the current. The oxygen attacks the zinc Z (the positive metal) and forms oxide of zinc; the hydrogen accumulates on the copper K (the negative metal) and in a short time covers the plate. All the oxygen accumulates on the zinc, and all the hydrogen on the other metal. The same holds good also when, as is shown in Fig 30, the current outside the battery passes through a fluid. If, for instance, the positive current enters through the closing wire E to plate L, made of zinc, platina, or some other metal, into the water A, and out again through the metallic plate D, then the oxygen accumulates at L and the hydrogen at D.

Hence it follows that the metallic surfaces of the zinc and

copper become separated from the conducting fluid, and instead of the former metallic contact between the fluid and the plates, a contact of oxide of zinc and hydrogen sets in, and the original current very soon loses its strength and almost disappears after a short time. The same thing takes place to a greater extent in the ordinary voltaic battery, because, owing to the more active analysis of the water which the stronger current produces, the oxygen unites with the zinc to produce oxide of zinc, and the hydrogen, in the form of small bubbles, covers the copper; hence, instead of the original zinc-copper battery, we have a combination of far weaker electromotors, viz., zinc-hydrogen.

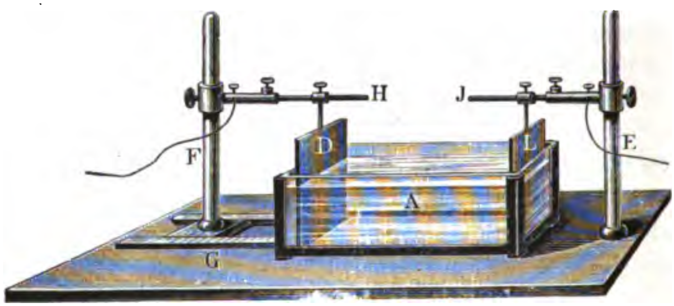


Fig. 30.

If we put in a vessel A, containing acidulated water (Fig. 30), two platina plates, D L, and connect them with the pole wires F E of any galvanic battery, the water between the platina plates becomes likewise decomposed; the oxygen is carried to the positive, the hydrogen to the negative platina plate. As the oxygen here does not unite with the platina, both gases, the mixture of which is styled inflammable gas, rise at the platina plate from the fluid. Several other compound bodies, like water, are decomposed by the galvanic current, and in this capability of the liquid conductor of being decomposed is to be found the principal reason for the unsteadiness of the earlier voltaic batteries.

CHAPTER VII.

SULPHATE OF COPPER BATTERIES.

In the simple combination of zinc and copper with a moist conductor, described in Chapter VI, we saw that, owing to the decomposition of the water, oxide of zinc and hydrogen gas was immediately formed round the copper plate, by which the negative plate became polarized and the current weakened. If, instead of pure water, we use a mixture of water and sulphuric acid as a conductor, a similar analysis of water occurs, but the oxide of zinc combines with the not so easily decomposable sulphuric acid, and forms a sulphate of zinc, which is dissolved by the remainder of the fluid. In this way the metallic surface of the zinc is kept clean so long as there is sufficient water to dissolve the sulphate of zinc which has formed there. The injurious effect of the hydrogen, however, which surrounds the copper plate, and prevents the direct contact of its surface with the fluid still remains; the only thing that can be done to remove it is to surround the negative metal (the copper plate) with a material that readily absorbs the approaching hydrogen, and thus prevents its adhering to the metal. As the hydrogen at the moment of its separation readily unites with the oxygen, the copper plate is surrounded with a material abundant in oxygen, which then transfers a portion of the oxygen to the hydrogen which the current has separated, and causes a re-combination of both gases into water. Hence, the negative metal remains unchangeably in contact with the fluid, and as this is also the case with the positive metal (the zinc), the action of such a galvanic combination remains constant, until either the sulphate of zinc is no longer soluble and the zinc plate becomes covered by it, or the oxygenous material around the copper plate is decomposed.

Daniell was the first to construct batteries of this kind. In order that the oxygenous material which surrounds the negative metal may not mix with the fluid which surrounds the zinc, all these batteries require two cells, or their equivalent. The zinc always remains in acidulated water, and the electro-negative metal in the oxygenous fluid, which is separated from the former by means of a porous cell or partition, insuring a conducting connection with it.

THE DANIELL BATTERY.

The Daniell element consists in its present form, as represented in fig. 31, of a vessel, in which stands a porous clay

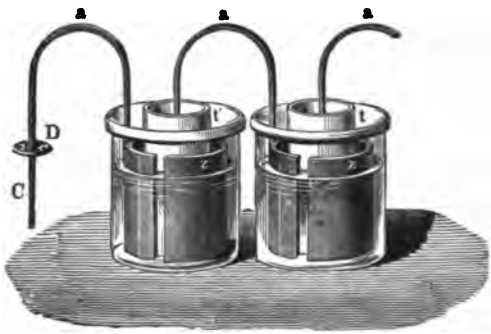


Fig. 31.

cylinder, *t*. The latter is surrounded by a zinc cylinder, *z*, whilst in the clay cell, *t*, a thin sheet of copper is suspended, which is attached to the copper wire, *a*, connected with the zinc cylinder of the next element. At the upper part of the copper sheet, C, a sieve-like perforated copper plate, D, is attached, which serves the purpose of holding the sulphate of copper crystals.

In charging the Daniell battery the glass vessel and the porous cup of each element is filled with water, and crystals of sulphate of copper put on the copper plate D. In about an hour afterwards enough sulphate of copper will have been dissolved to put the battery in action. As soon as the circuit is closed,

owing to the decomposing process which sets in simultaneously with the current, sulphate of zinc is formed in the zinc cups which is decomposed by the water in the cup. The released hydrogen, however, is conducted towards the copper plate in the porous cup, where at the same time a corresponding portion of the sulphate of copper is thrown down in sulphuric acid and the black oxide of copper; the former remains undecomposed, and the latter becomes separated into copper and oxygen. The oxygen which is released from the black oxide of copper and hastens towards the zinc plate meets the hydrogen which starts from the zinc cup; both gases combine, forming water, and the formation of a hydrogen gas around the copper cylinder is thereby prevented. The pure copper which is left from the oxide of copper after the secretion of the oxygen is conducted by the current to the copper cylinders, where it is deposited in a coherent mass.

The maintenance of the Daniell battery requires only the occasional dropping of new crystals of sulphate of copper in the porous cups, to keep the solution at the point of saturation, and an occasional change of the water.

The construction of a Daniell element permits of a variety of different forms. Both vessels may be interchanged; the glass vessel, G (fig. 32), may be filled with sulphate of copper, and the porous cell, P C, contain the zinc, Z; and in order that the action of the battery may commence at once, the copper cups may be filled with a concentrated solution of sulphate of copper and the zinc cells with acidulated water.

The Daniell battery is scentless, and does not develop any poisonous vapors, and, hence, may be used anywhere without fear of endangering health or acting disadvantageously on the metallic parts of the surrounding apparatus.

It is especially adapted to telegraphic apparatus worked upon the closed circuit plan, but less suitable for open circuits, because in the latter case a good deal of metallic copper is formed at the bottom of the porous cups, by which the cups themselves become spoiled and the current is weakened.

But even in a closed circuit the porous cups of a Daniell battery, when used for a long time, are apt to be covered with copper on the side turned towards the copper plate, which often penetrates through the cells, and makes them brittle; and on account of a conducting connection by some solitary thread between the zinc and the copper plate, the activity of the respective elements is very considerably retarded. Contrary to the general opinion that these deposits of copper are produced by the circulating current, and tend to increase the strength of

Fig. 32.

the battery, it has been proved that they have nothing to do with its activity. For several days a powerful current may be kept up without any visible mark of this copper coating being noticed on the cups, whilst, on the other hand, in a few days on an open circuit, ten to thirty grains of coating may be obtained, if the battery is filled with the fluid in the usual way, but if no copper or zinc cylinder is put in, there will be no visible coating of the cups; hence, it does not originate through an action of

both fluids on each other. Neither does it appear when the copper cylinder only is inserted; it appears, however, after the zinc plate is put in, it being thus obvious that this is substantially required.

It is a well known fact that iron put in a solution of sulphate of copper precipitates the metallic copper. Dip a small piece of iron, even for a short time, into a solution of sulphate of copper and it will become red, and closely coated with metallic copper. Now, all the zinc of commerce contains, besides other metals, iron, which, as experience teaches, when mixed with zinc, lead and so forth, cannot be dissolved by diluted sulphuric acid, but coats the zinc with a loose gray stratum, which gradually, as a gray deposit, falls to the bottom. Likewise by giving an oblique direction to the zinc plate, it will soon be found clinging in larger or smaller quantities to the sides of the porous cells. But, as the porous cups after a time become impregnated with the sulphate of copper, the latter becomes chemically reduced, and metallic copper is formed on the former. The first copper stratum that is formed in this way comes in direct contact with the metallic copper deposit, formed in the sulphate of copper solution, and following the thread, penetrates through the porous partition and expands itself outside of it in a solid mass. The process of penetration through the porous cell always commences at the side turned towards the zinc, which can easily be shown; for, if the cells are filled in the usual way, and some zinc deposit is placed in it equally divided on both sides of the cups, the copper efflorescence on the side of the clay cell which was turned towards the sulphate of copper will not appear until some hours afterwards. The penetration of the copper through the porous cups may be prevented by coating them with wax over the bottom, and on the lower sides about a quarter of an inch high, and removing the zinc deposit every two or three days with a metallic brush. The penetration of the sulphate of copper in the porous cups may be decreased, if the acids are poured in four or five hours previous to the sulphate of copper solution.

The great superiority of the Daniell battery for general use led to a series of alterations, all of which were intended to obviate the inconveniences which we have alluded to, and which are connected with the use of a porous cup. We shall describe the more important of them, which are still retained in use.

THE SIEMENS-HALSKE BATTERY.

The Siemens-Halske's element, which is a modification of the Daniell, differs from the latter substantially in the improvements in the diaphragm. It is represented in fig. 33.

Fig. 33.

A A is a glass vessel, *c c* a glass tube, *k* a perpendicular copper plate bent into spirals, *b* a wire attached to it, *e e* a thin pasteboard disc, *f f* the diaphragm in place of the porous cell formed of a peculiarly prepared mass of paper, Z Z a zinc ring with clamp *h*. The mass of paper must be well compressed, and afterwards a fourth part of its weight of sulphuric acid poured over it and stirred up until the whole mass has become homogeneous and glutinous. Then four times as much water is added to it, and worked with it; the superfluous sour water is removed under pressure.

The inner glass cylinder *c c* is filled with crystals of sulphate

of copper and water poured on it, and the ring-shaped intermediate space filled with water, to which is added, on the first filling, some acid or common salt. Afterwards it is only necessary to keep the inner cylinder always filled with crystals of sulphate of copper, and now and then renew the water in the outside vessel. The sulphuric acid required to form the sulphate of zinc is conveyed by the current itself through the diaphragm, and simultaneously removed through it by the sulphuric acid which is set free by the decomposition of the sulphate of copper.

The cost of maintenance of this battery is very small, as all chemical consumption of zinc and copper is prevented in consequence of there being no local action. It may be left standing for months without impairing its action, if good care is taken that crystals of sulphate of copper are kept in the glass tube *c c*, and the diluted water replaced. The zinc is not amalgamated. In order to keep the foreign metals contained in the zinc separated from the mass of paper, the latter is covered by a ring, *g g*, of coarse cloth, which is replaced by a new one when the battery is cleaned, which ought to take place every fortnight. These elements have generally too much resistance for local batteries, but they are admirably adapted for working long lines.

THE MEIDINGER BATTERY.

The Meidinger element is a modification of the Daniell battery, but it has no porous cell, and possesses greater durability and constancy of current. It consists, as shown in the engraving (fig. 34), of a glass vessel, A A, 8 inches high and 5 inches wide, in the bottom of which is placed a small glass vessel, *d d*, of half the dimensions of the larger glass, cemented in with rosin. A zinc disk, Z Z, which is supported upon a ledge of the outside vessel, surrounds the smaller glass. The inside wall of the smaller glass, *d d*, is covered by a sheet of copper, *e*, on the lower end of which an insulated copper wire, *g*, is riveted. The mouth of the vessel is closed by a wooden or tin plate

having an opening in the centre for the reception of a glass cylinder, *h*, 1½ inches in diameter and 8 inches high, narrowing towards the lower end, which is rounded, and in which a hole is made. This tube is sunk to the centre of the small glass, *d d*. The entire vessel is filled up to the zinc disk, about 1½ inches below the upper brim, with a diluted solution of Epsom salts. The glass cylinder, *h*, in place of which a glass funnel can be used, is filled with crystals of sulphate of copper, forming a concentrated solution, which, being a heavier fluid, sinks down through the small hole in the glass tube, and fills the small glass, *d d*, to the centre.

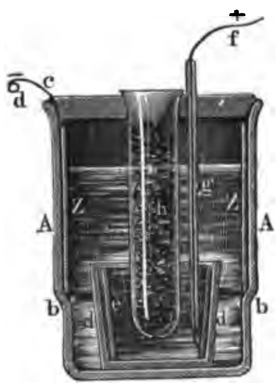


Fig. 34.

There is very little diffusion of the copper solution upwards, or out of the little glass vessel, *d d*, to the zinc disk, Z, even when the battery is not in operation; so that, after the lapse of several weeks, the zinc scarcely shows any signs of being affected by the copper. The battery is, therefore, much superior to the ordinary Daniell battery, which, when the circuit is open, produces a great diffusion of the sulphate of copper through the porous cup.

The zinc is usually amalgamated on its inner side, enabling its impurities to be easily removed, which would otherwise form a hard crust. If the copper wire, *g f*, which is riveted to the

copper sheet, *e*, is connected with a small strip of copper, *c d*, soldered to the zinc disk, we obtain a galvanic current having an electromotive force equal to that of a Daniell cell, and it remains constant as long as there is sulphate of copper in the glass tube, *h*, and the zinc, Z, is not dissolved. During the activity of the battery, in fact, the solution of sulphate of copper increases a little in quantity, in consequence of a diffusion which is caused by the overflowing (in the smaller glass, *d d*) of the heavier sulphate of zinc solution formed by the dissolution of zinc. By the action of the current the greater part of the copper is deposited on the upper half of the copper plate. A trace of copper, however, appears upon the zinc, but frequently this is after several weeks' operation. The duration of the battery depends on the size of the glass vessel. A battery of the size described (according to Meidinger's statement) ought to be taken to pieces and the solution of Epsom salts and sulphate of zinc drawn off, and pure water put in it as soon as it has consumed three pounds of sulphate of copper, which, however, may take a year.

The resistance of this cell considerably exceeds that of the Daniell; but for a line battery, where the resistance in the wire is very considerable, this is of no special importance. Meidinger recommends, for main lines, cells 5 inches high and 3 inches wide, while the battery of the size depicted in our engraving is intended for local use and for line batteries of small resistance. As a local battery for the Morse telegraph, it is best to use six cells, two of which are connected with like poles, so that we have, practically, three elements with enlarged surface and conductivity.

Generally, in charging the Meidinger element, a solution of one part of Epsom salts to four or five parts of water may be used. In proportion to the activity of the battery and the consumption of the sulphate of copper, fresh crystals of this salt should be added to the contents of the glass funnel; but when the surface of the fluid has sunk by evaporation, soft water only need be added to the glass funnel. An improvement has

been obtained in this element by having the funnel shaped sulphate of copper vessel entirely closed at the top. After the jar, *h*, has been charged with crystals of sulphate of copper, a solution of Epsom salts (sulphate of magnesia) is added thereto.

The Meidinger battery is valuable wherever long duration and a current of moderate but constant strength is required, and especially for operating the Morse telegraph, electrical clocks, hotel telegraphs and electric bells. The chief condition for its successful use is that it shall not be shaken, as shaking causes a mixture of the fluids, and in this way destroys its action and the constancy of the current. Its faults consist in the liability that the tube *h* may be filled up with sulphate of copper (either from impurities of the salt or from precipitation of metallic copper) or crystals of sulphate of zinc, so that the action of the element ceases; and partly because the flow of the solution of sulphate of copper from the tube to the lower edge of the zinc cylinder rises, and then, at the least diffusion, the sulphate of copper attacks the zinc. When this happens, the sulphate of copper is decomposed by the zinc, a superfluous quantity of sulphate of zinc is formed in the fluid, and metallic copper is precipitated in the form of a brown, spongy powder upon the zinc cylinder. This battery is extensively used upon the Austrian telegraph lines.

THE GRAVITY BATTERY.

In consequence of the inconvenience experienced in the use of the Daniell battery from the deposit of copper upon the porous cell, Cromwell F. Varley, in 1854, endeavored to discover some process by which it could be suppressed altogether without diminishing the force of the battery or lessening its constancy. In this effort he was entirely successful, for after a series of experiments he found that the difference in the density of pure water, or water charged with sulphate of zinc, and a solution of sulphate of copper, was sufficient of itself to cause an entire separation between them when placed

in the same vessel. Accordingly he constructed his battery (fig. 35) by suspending a cylinder of zinc near the top of a glass jar, and placing a copper plate at the bottom, and then filling the jar with a saturated solution of sulphate of copper and a diluted solution of sulphate of zinc. The difference in the specific gravity of the two solutions causes them to separate at once and become superposed in the jar, the sulphate of copper occupying the lower and the sulphate of zinc the upper portions of the jar.

Fig. 35.

The chemical action which takes place in this battery is the same as in the Daniell. The zinc cylinder is oxidized by the oxygen of the water, and the oxide combines with the acid set free by the solution of sulphate of copper, forming sulphate of zinc, which remains in solution, while the oxide of copper, which was previously combined with the acid, being set free, is reduced to metallic copper, and is precipitated on the surface of the copper plate at the bottom of the jar. The reduction of the oxide to the metallic state takes place in the following manner: The water of the solution furnishes oxygen to the zinc, and thus enables it to combine with the acid; while the hydrogen, which is liberated, again forms water with the oxygen of the

oxide of copper, with which it comes in contact, leaving the metal free. Hence, but little gas is given off during the action of a battery charged by sulphate of copper, as the hydrogen is in this case mostly absorbed.

In order to reduce the resistance of the gravity battery, the horizontal copper plate is now supplemented by two vertical copper plates, forming a X, and projecting about three inches f.om the bottom of the jar.

In charging the battery the copper frame is placed on the bottom of the glass jar, and the jar filled with sulphate of copper to the top of the copper frame, and with water to within an inch and a half of the top of the jar.

The battery must then stand until the sulphate of copper and sulphate of zinc dissolve and separate. When the two solutions have properly separated the lower part of the jar will contain a blue fluid, and the upper part a nearly colorless or transparent fluid. After the separation of the two fluids (which will require about forty-eight hours) the brass frame for holding the zinc must be placed on top of the glass jar, and the zinc suspended near the top. The zinc should always be suspended in the colorless or transparent fluid.

In case the zinc is placed in the jar before the two solutions have separated, copper will be deposited on the zinc, and the action of the battery be retarded. When such deposits take place the zincs should be removed and cleaned with a stiff brush.

As the sulphate of copper becomes dissolved and consumed the blue solu ion will decrease, and the zinc should be lowered from time to time, so as to reduce the internal resistance.

When the water in the upper portion of the jar becomes saturated with sulphate of zinc, the sulphate crystallizes upon the zinc plate, stopping the action of the battery. The conducting power of a solution of sulphate of zinc is greatest when diluted with an equal quantity of water. Part of the solution, therefore, should be from time to time removed and replaced by water.

When crystals form on the top and sides of the cell, in consequence of the water being saturated with sulphate of zinc, they

should be removed with a damp cloth. A little grease or fat rubbed on the top and sides of the jar, near the top, will have a tendency to prevent the formation of crystals.

When all the sulphate of copper has been consumed the action ceases, and sulphate of zinc will be reduced upon the copper plate as a black powder. It is necessary, therefore, to provide a constant supply of sulphate of copper. Undissolved crystals of sulphate of copper should always remain in the bottom of the jar.

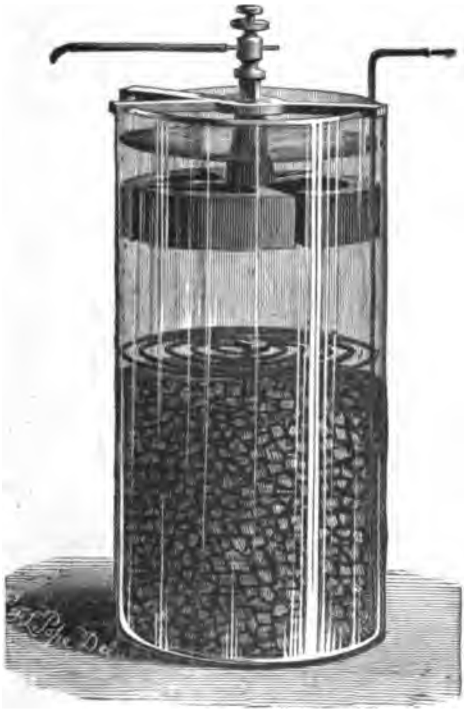


Fig. 36.

The jars should not be disturbed when in use, as this would cause the solutions to mix. As the water evaporates from the jar it should be replenished by a fresh supply. Great care must

be taken in replenishing the jars not to disturb the lower or sul phate of copper solution.

Two sizes of the battery are made, one of which is designed for local batteries and for working from three to five main wires, and the other for working one or two main wires.

The battery should be taken down and cleaned about every four months.

The battery should be kept in a dry and comparatively warm place. The temperature of the battery should never be allowed to approach the freezing point, as this would destroy its action.

A form of gravity battery is shown in Fig. 36, in which the negative element consists of two flat spirals of copper wire, and in another variety, Fig. 37, two copper disks are used in place of the spirals.

Fig. 37.

THE MENOTTI BATTERY.

The Menotti element is composed of an earthenware or glass cell, having a flat circular plate of copper laid at the bottom, with a piece of gutta percha covered wire soldered to it, which comes out of the cell and forms the positive pole; crystals of sulphate of copper cover the copper plate, upon which is placed a layer three inches thick of sawdust, and upon the sawdust a

zinc plate. The cells are usually about 4 inches diameter inside and 5 inches high. The metal plates are about $3\frac{1}{2}$ inches in diameter. This form of battery is portable, and has a constant electromotive force. Its resistance is high, being usually about 20 ohms when in fair condition. It is chiefly used for testing

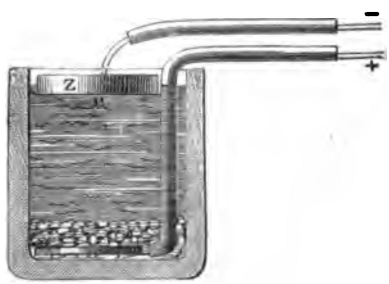


Fig. 38.

purposes, and is well adapted for use at sea, where the wash of the solution tends to disturb the electromotive force and to produce variable polarization; for even in a Daniells cell there is always practically some polarization. In principle, this battery does not differ from the gravity battery—the only variation is in the use of the sawdust.

SIR WILLIAM THOMSON'S BATTERY.

The Menotti battery is said to have been first introduced by Sir William Thomson for testing the Atlantic Cable in 1858. He subsequently devised an excellent form of this battery for experimental or other purposes, requiring very low internal resistance, combined with convenience and economy of management, known as the tray battery. The coppers are made in the form of trays with inclined sides, 18 or 20 inches square and about 3 inches deep, each tray resting directly upon projections cast upon the upper surface of the zinc of the cell beneath. The zinc is usually made in the form of a grating. To avoid the inconvenience which was found to arise from the cells being occasionally eaten through by the action of the solution, they are

now usually made of wood and lined with sheet lead, electrotyped with copper at the bottom.

Another very convenient and useful modification of this battery is shown in figures 39 and 40. It consists of a containing vessel of sheet lead, in the bottom of which is placed five or six pounds of sulphate of copper. This is covered with a layer of

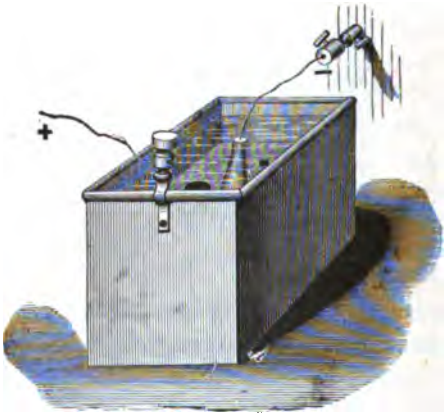


Fig. 39.

clean pine sawdust from one to two inches thick, upon which the zinc plate rests. The vessel is then nearly filled with soft water, or, if quick action is desired, a solution of sulphate of zinc.

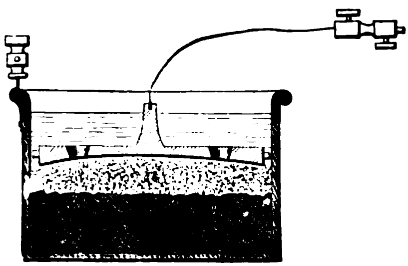


Fig. 40.

This battery is so simple in construction and arrangement that the most unskilled can readily be taught to manage it, while it will remain in action and give a strong and perfectly uniform

current from three months to a year (according to the work done by it), without any attention whatever. The internal resistance is very low, and it is well adapted to working circuits of small resistance where comparatively strong and continuous currents are required.

THE MUIRHEAD BATTERY.

This is a form of sulphate of copper battery, fig. 41, now in general use for telegraphic purposes in England. The zinc plates are about 4 inches long by 2 inches wide, and the copper plates about 4 inches by 3 inches. The porous cells are filled

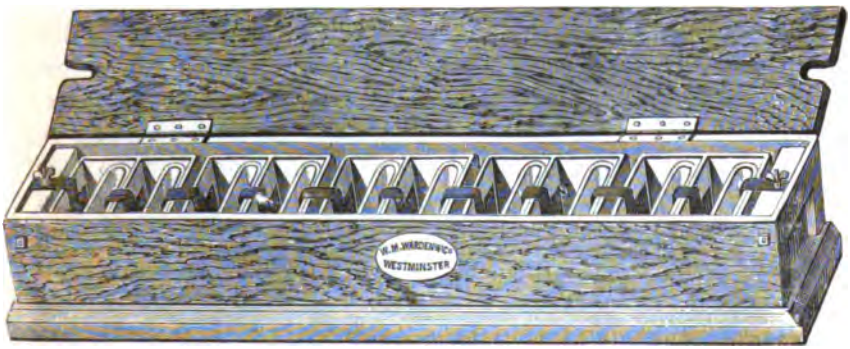


Fig. 41.

with a solution of sulphate of copper, and the outer cells, which are made of white porcelain, and in pairs, are filled with very dilute sulphuric acid. Five such pairs are enclosed in a strong teak-wood case, with a lid through which gutta percha covered wires pass at the ends. Crystals of sulphate of copper, of the size of a hazel nut, are placed in the porous cells to maintain the solution in a saturated condition. The copper connecting strap is cast in the zinc, having been tinned to insure adhesion. To check endosmosis, or the tendency of the two fluids to mix through the porous cells, they are greased, except on the portion which is opposite the zinc plate. This, however, does not entirely prevent the mixing of the solutions.

CHAPTER VIII.

NITRIC AND CHROMIC ACID BATTERIES.

THE most powerful voltaic combinations known are those in which some of the mineral acids are employed as excitants, especially nitric, chromic and sulphuric acids.

THE GROVE BATTERY.

This battery was, until quite recently, in general use in this country for working telegraph lines. It consists of a hollow cylinder of zinc, about three inches high and two in diameter, coated with an amalgam of mercury, and having an opening on one side to allow a free circulation of the liquid. The zinc cylinder has a projecting arm, to which is attached a strip of platinum about one inch wide and three inches long, and having the thickness of tin foil. The zinc cylinder is placed in a glass tumbler containing sulphuric acid, diluted with about twenty times its bulk of water. Within this cylinder is placed a porous cup made of earthenware, baked without being glazed, and filled with strong nitric acid. This cup allows liquids to pass slowly through it, and, when wet, offers but little resistance to the electric current. Within this cup is suspended a strip of platinum fastened to the end of the zinc arm projecting from the adjoining zinc cylinder. Fig. 42 represents a Grove battery, consisting of forty such combinations, each cell being completely insulated and arranged upon a stand. The stand has four girders and fifteen holes in each girder. In the holes are placed oaken pins, to which are attached glass insulators with wooden shields, the latter supporting the battery cells. The stand, pins and shields are well coated with asphaltum, and the glass insulators dipped in paraffine.

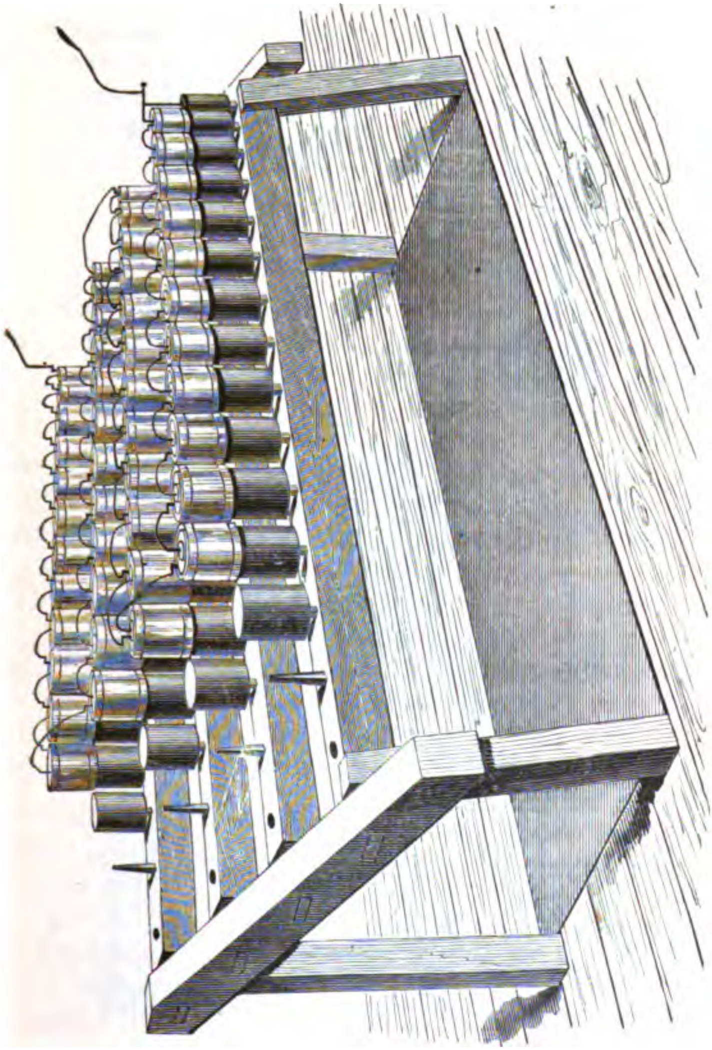


Fig. 42.

When the Grove battery is in action sulphate of zinc is formed in the outer cell, and the heavy brown gas, peroxide of nitrogen, is given off by the nitric acid. The peroxide of nitrogen discharged at the platinum plate is absorbed by the nitric acid, in which it is soluble, so that the plate is left free. The resulting solution is highly conducting. The peroxide of nitrogen soon spontaneously separates from the nitric acid, giving rise to the dark brown vapor already mentioned.

THE BUNSEN BATTERY.

The Bunsen zinc-carbon element replaces the expensive platina of the Grove battery by a mass of carbon made up in the shape of a hollow cylinder, peculiarly prepared.

Fig. 43.

Figs. 43 to 46 represent it in its parts and construction.

As will be seen from fig. 43, a carbon cylinder, open at the bottom, is put in a glass vessel, which becomes narrower towards the top; in the hollow of the carbon cylinder is inserted a hollow, porous clay cylinder, closed at the bottom. A ring, *a*, is closely laid around the upper part of the carbon cylinder, extending beyond the glass vessel; this ring is attached to the hollow cylinder *c*, made of rolled zinc. Ring *a* is made of copper, and, as fig. 44 shows, may either be closely fastened to the carbon cylinder at *a*, or by means of the copper cross-bow and the screw *b*, may be coupled to the zinc cylinder at pleasure.

The porous clay cup, which stands inside the carbon cylinder, is filled with diluted sulphuric acid, and the glass vessel in which the carbon is to be found, with concentrated nitric acid.

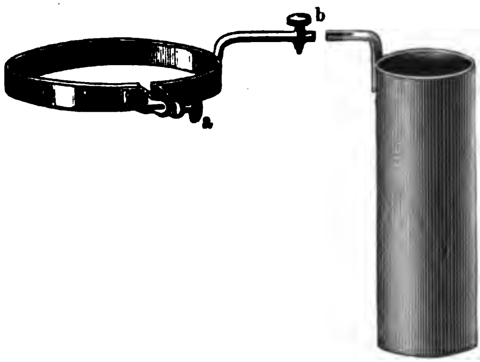


Fig. 44.

Zinc cylinder *c*, of one of the elements. hangs in the porous cup filled with sulphuric acid of the next element. How these separate elements are connected into a battery is shown in fig. 45.

Fig. 45.

The zinc cylinder of the first glass is connected with the copper strip or the carbon cylinder of the second glass, the zinc

cylinder of the second glass with the copper strip of the third glass, and so forth. Finally, the zinc cylinder of the last glass, with its strip *n*, projects out of the battery and forms the — pole, just as the copper strip *p* of the first glass forms the + pole. The positive current passes in this battery, in the closing wire, outside the fluid, from carbon to zinc.

J. Stöhrer, of Leipsic, has considerably improved the carbon battery. Fig. 46 gives a view of such an element.

Fig. 46.

The cylinder, consisting of very solid and compact carbon, has on the top a projecting edge, which rests upon the edge of the glass vessel which surrounds the cylinder, and is provided with a heavy copper ring. This ring does not serve the purpose, as in those formerly constructed, of taking up the current from the carbon cylinder, but it is the mere bearer of a strip, *a*, in which is located a binding screw, *r*. Opposite to this screw

the carbon lays bare, and at p^1 the curve is transformed into a plain surface, in order to present a flat contact to the connecting part of the nearest zinc. The zinc is cross-shaped (a convenient form for casting), and should be properly amalgamated—that is to say, covered with quicksilver. It terminates in a round neck, in which the connecting wire is soldered.

The wire terminates in a heavy copper strip, p, which may be covered with platina on the side connected with the carbon cylinder between p^1 and r^1.

The projecting edge of the carbon cylinder is soaked in wax, and the ring covered on the inside and outside and cemented with wax and resin, mixed in equal parts. As the plate p, covered with platina, takes up the current direct from the carbon, the main inconvenience of the former carbon batteries, namely, that the copper rings, which serve the purpose of taking up the current, oxidized very quickly, and then made very bad conductors, is obviated.

The Bunsen element develops, like the Grove, a very powerful current, but it has the great disadvantage, in common with the latter, that in using it there is evolved a heavy brown gas—peroxide of nitrogen—which is injurious both to the health and to the apparatus, and makes it unfit for general use.

Siemens-Halske zinc carbon element is represented in fig. 47. e is the carbon cylinder, of $4\frac{1}{2}$ inches high, $2\frac{1}{6}$ inches inside and 3 inches outside diameter; c the porous clay cup, of $4\frac{1}{2}$ inches high and 2 inches outside diameter; d the zinc cast in the ordinary cross shape, to which the copper wire s is soldered, which is to be connected with the carbon of the nearest element by means of clamp screw f. Around the upper part of the carbon cylinder a leaden ring about $\frac{3}{4}$ of an inch wide is laid, and around the latter a copper ring of the same width, which is separated and carries on both its ends flanges, which may be moved towards each other by means of a screw, and thus press the leaden ring closer to the carbon cylinder. The copper ring carries the prolongation v, on which clamp f is attached, by means of which the carbon cylinder is connected with the zinc of the

nearest element. The entire system stands in glass *a*, whose form is to be seen from the drawing.

The solutions for this carbon battery for telegraphic purposes consist of sulphuric acid diluted with 15 to 20 parts of water, both for the porous cups holding the zinc, as also outside of them for the carbon cylinder. In both cases the zinc should be amalgamated very carefully.

Fig. 47.

A Bunsen battery of the latter kind, with diluted sulphuric acid in the zinc as well as copper cell, produces for some time a pretty constant current, if it is not kept closed too long, and, hence, it is very convenient for a telegraph line, which, when not in operation, leaves the battery open, and for working purposes requires only a momentary closing. If, however, they remain closed for some time, the carbon cylinder becomes coated

with a layer of hydrogen which retards the conduction of the current in the inside of the battery, and even interrupts it.

In such cases the current of the battery is no longer constant. Even on open circuits its strength is soon exhausted, if it is kept in pretty constant action, by the rapid formation of sulphate of zinc. In Prussia, where these batteries were formerly in pretty general use for working telegraph lines, they required to be renewed every five weeks. The carbon cylinders and the porous cups of the old elements require to be soaked in warm water to remove the salts with which they become impregnated.

The carbons for Bunsen's battery are made by a process invented by Bunsen. The fine dust of coke and caking coal is first put into a close iron mould of the shape required for the carbon and exposed to the heat of a furnace. When taken out the burned mass is porous and unfit for use, but by repeatedly soaking it in thick syrup or gas tar and reheating it, it at length acquires the necessary solidity and conducting power. The carbon that forms on the roof of gas retorts is harder and better than the carbon thus made, but it is difficult to work, and the supply of it is limited.

FAURE'S CARBON BATTERY.

In this battery an outer jar contains a solution of common salt and a zinc cylinder. Inside the zinc cylinder is the carbon pole, which is made in the form of a bottle, and is filled with concentrated nitric acid. This bottle is closed by a carbon stopper to prevent the escape of fumes, and performs the double function of porous pot and of carbon pole; the nitrous gas rises inside the bottle and increases the pressure, forcing the acid through the porous cell in sufficient quantity to keep up the action.

CHROMIC ACID BATTERY.

A modification of the Bunsen battery is in use, in which a solution of bi-chromate of potash and sulphuric acid takes the place of the nitric acid. This solution is made by dissolving

one pound of bi-chromate of potash in ten pounds of hot water, and when cold adding five pounds of strong sulphuric acid. As this addition causes the solution to become warm, it must be allowed to cool before being used.

The zinc is placed in a saturated solution of common salt, which is made by adding salt to the required quantity of water until it ceases to dissolve any more.

The chlorine of the common salt unites with the zinc, forming chloride of zinc; while at the carbon electrode the sodium replaces hydrogen in sulphuric acid, forming sulphate of sodium. The nascent hydrogen reduces chromic acid (produced by the action of sulphuric acid on the bi-chromate of potash), so that sulphate of chromium is produced.

THE GRENET BATTERY.

The single fluid bi-chromate of potash or Grenet battery (fig. 48), is a very good form of an experimental battery where con-

Fig. 48.

stancy of current is not required, as, for example, in the laboratory and mechanical workrooms. The cell is in the form of a bottle, and contains a mixture of 2 parts of bi-chromate of potash,

dissolved in 20 parts of hot water and 1 part sulphuric acid. The top is provided with a brass frame, to which is fastened a wooden cover. To this cover are attached two carbon plates which permanently dip into the fluid; and between the carbon plates a zinc plate is suspended, which may be plunged into the fluid or withdrawn at pleasure. When the zinc is withdrawn, the action ceases. The battery gives a powerful current for a short time, but rapidly polarizes. The length of time during which the fluid will retain its power depends upon the use which is made of the battery. It is not suitable for continuous use; but in all cases where a powerful current is required for a brief period, it is a very desirable and economical apparatus.

ELECTRO-MOTIVE FORCE OF THE VARIOUS ELEMENTS.

The electro-motive force of a galvanic element is proportional to the intensity of chemical affinity, or the force tending to chemical action. The electro-motive force of each of the various sulphate of copper elements, described in Chapter VII, is the same as that of the Daniell, 1.079 volts. The electro-motive forces of the several elements described in this chapter differ considerably from each other, although they are in all cases greater than in the combinations previously described. The electro-motive force of the Grove element, measured in volts, is 1.956; Bunsen's, nitric acid, 1.964; Bunsen's, chromic acid, 2.028; Faure's, 1.964; Grenet, 1.095.

CHAPTER IX.

SINGLE FLUID BATTERIES.

THE single fluid batteries are well adapted for use on what are termed open circuits—that is, circuits which are only closed occasionally and for but a few moments at a time. Some of the forms, however, answer an excellent purpose upon telegraphic or other circuits of great length or high resistance. They are also exceedingly convenient for experimental purposes, or, in fact, for occasional use of any kind.

THE SMEE BATTERY.

This battery was made upon observing the property which rough surfaces possess of evolving the hydrogen, and smooth surfaces of favoring its adhesion. Thus, whatever metal is used for the negative plate is roughened, either by a corrosive acid or mechanically by rubbing the surface by sand paper. The liquid generally used to charge this battery is 1 part sulphuric

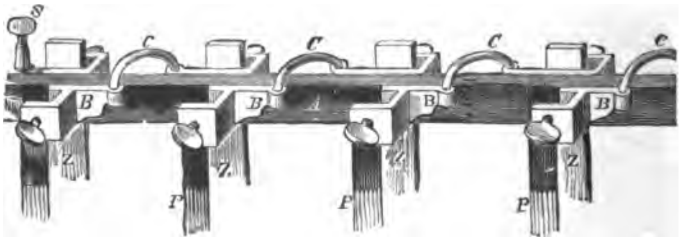


Fig. 49.

acid to 10 of water. The form of battery used for telegraphic purposes consists of a strip of platinum, one inch wide by ten in length, fastened to a beam of wood, upon the opposite side of which is a plate of zinc covered with mercury, and both plunged

into a glass vessel. In arranging a series of cells, the zinc of the one cell is attached to the platinum of the next. Figs. 49 and 50 represent the battery as formerly used in working telegraph

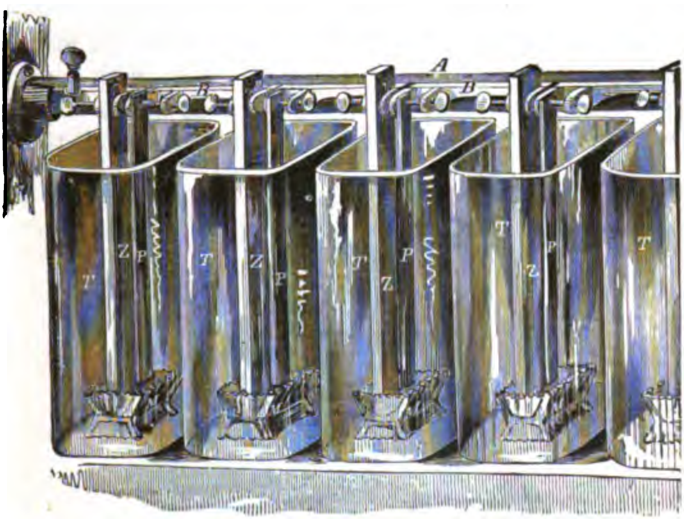


Fig. 50.

lines. A is an insulated wooden bar; B, brass clamps; Z, zinc plate; P, platinized silver plates or strips of platinum; T, glass cells. In fig. 49 the wooden bar rests upon the glass cells; in fig. 50 the bar rests on iron brackets fastened to independent supports.

THE LECLANCHÉ BATTERY.

The + pole consists of a carbon plate which on its upper end is coated with rosin, and provided with a binding screw; it stands in a porous cup, which is filled with a coarse grained mixture, of the needle form of peroxide of manganese and carbon, the residue of gas retorts.

The — pole consists of an amalgamated zinc rod; both poles stand in a diluted solution of sal-ammonia, which is poured into the outside glass vessel.

When the element is closed the current in the zinc cup decomposes the water and the sal-ammoniac, and in the carbon cell the manganese. In the zinc cell chloride of zinc is formed, which dissolves; the hydrogen of the decomposed water is neutralized by an equivalent of oxygen which the manganese gives up; the hydrogen of the chlorine unites with the oxygen of the decomposed water. Hence the zinc, as well as the carbons, always maintain a good conducting connection with the fluid,

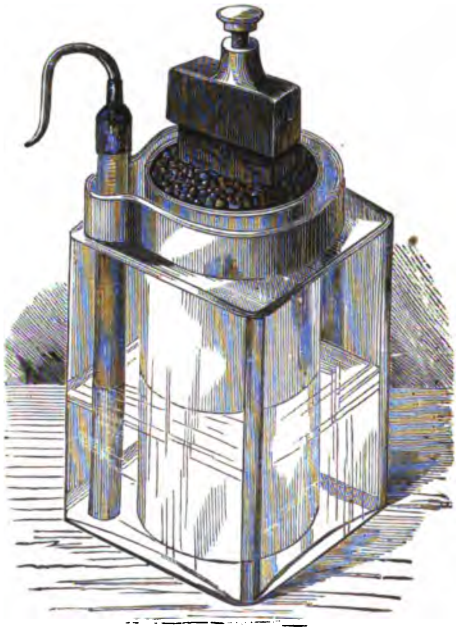


Fig. 51.

and consequently the strength of current upon circuits of considerable resistance remains constant for a pretty long time.

Leclanché's element has been employed for the past seven years on several French and Belgian railroads, and is also used elsewhere very successfully for telegraphic purposes, hotel annunciators, and so forth. The internal resistance of the element is

hardly $\frac{1}{8}$th of that of a mercury element of the same size; while the electro-motive force of 25 cells is equal to 40 Daniell elements.

In practice, for every 50 grains of zinc dissolved, 100 grains of sal-ammoniac are consumed and 100 grains of manganese peroxide are reduced. There is no waste of material when the battery is not in action, so that, if the evaporation of the liquid is prevented, it may be allowed to remain untouched for months without losing power. It is well suited for a telegraph wire not in constant use and worked upon the open circuit plan, or for electric bells. It is not suitable for permanent currents or local circuits, because when placed in short circuit it polarizes very quickly.

The carbon plates are capped with lead to provide an attachment for the binding screws, as copper would be attacked by the ammonia; but a salt of lead is formed between the carbon and the metal which in time insulates them from each other. To prevent this the carbons are dried and heated to about 120° Centigrade; their tops are then dipped in melted paraffin and covered with lead, great care being taken to press the lead closely into contact with the carbon. It is not absolutely necessary to amalgamate the zinc, but the amalgamation tends to prevent the formation of crystals upon its surface. When the sal-ammoniac has nearly been removed from the liquid, it is unable to dissolve the zinc chloride, and in consequence becomes milky in appearance; more sal-ammoniac must then be added. When the battery begins to fail the porous jars may be soaked in water, but this process cannot be adopted a second time. The cell should not be filled more than two thirds of its depth.

THE MARIÉ-DAVY BATTERY.

Marié-Davy's quicksilver element is very successfully used in France at the present time. It is a zinc-carbon element, in which the zinc stands in pure water and the carbon in a paste of moistened proto-sulphate of mercury in a porous cup. The reduction in the inside of the element follows the same course

as the Daniell; the zinc becomes oxidized through the oxygen of the decomposed water, and the hydrogen which is set free reduces the oxide of mercury which proceeds from the decomposition of the sulphate. The sulphuric acid gets over to the oxide of zinc and forms sulphate of zinc, while the hydrogen goes to the oxide of mercury, uniting with its oxygen and forming water, and metallic mercury forms on the bottom of the porous cell. According to a French authority 38 elements were in uninterrupted activity for six months without requiring any cleaning or renewing whatever, the current being equal to 60 Daniell elements, while the dimensions were smaller than the Daniell, which, under the same conditions, only lasted three months.

Fig. 52.

The glass vessels were $3\frac{1}{2}$ inches high by 3 inches diameter; the zinc surface was $2\frac{1}{2}$ by $2\frac{1}{4}$ inches, and the porous cups $2\frac{3}{4}$ by $1\frac{3}{4}$ inches.

In another combination hyposulphuric oxide of mercury is used, which is insoluble in water, instead of the soluble muriate of mercury.

The sulphate of mercury is liable to rise by capillary action to the junction of the carbon and copper, and by attacking the copper destroys the continuity of the circuit. This is prevented by filling the pores of the charcoal at the top with melted paraffin.

While it is a powerful battery, and produces excellent effects, its maintenance is expensive, and it is not adapted for continuous work, owing to the slow solubility of the salt.

THE SULPHATE OF LEAD BATTERY.

The Sulphate of Lead Battery is also the invention of Marié-Davy. It is constructed in the form of a column and occupies but little room. It consists of a series of tinned iron pans *a*, *a*, *a*, provided with three arms placed horizontally at equal distances apart. The bottom of each pan rests upon a zinc disc, and is coated inside with pulverized sulphate of lead moistened with water. The pans are piled one above the other, between three wooden posts D, D, D, provided with iron screw heads, on which the pans rest by their three horizontal arms *c*, *c*, *c*. The wooden posts D, D, D are placed on a wooden frame E, F.

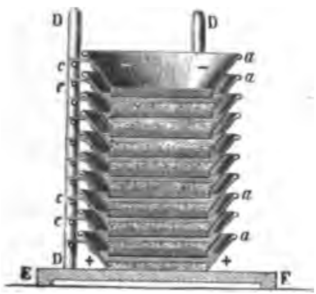


Fig. 53.

The battery is charged by pouring water into the iron pans, The sulphate of lead is almost insoluble in water, but it is a good conductor of electricity. The zinc is attacked, the leaden salt is reduced, and zinc sulphate and metallic lead is deposited on the bottom of each pan. The electro-motive force of this battery is inferior to that of Daniell, but in consequence of the great conductibility of the sulphate of lead, its resistance is much less, and the resistance still further decreases as the fluid becomes charged with sulphate of zinc. The battery is easily kept in order, it being only necessary to add water from time to time to supply the losses occasioned by evaporation. The current generated will be greater if a saturated solution of salt and water be used instead of common water.

Like the sulphate of mercury element the sulphate of lead battery loses its power very rapidly when worked upon a circuit of small resistance.

THE SAND BATTERY.

The batteries originally used to work the English telegraphs, and the Bain telegraphs in this country, were composed of amalgamated zinc and copper plates 4½ inches long by 3½ inches wide, the zinc being $\frac{3}{16}$ of an inch thick. The plates were cemented water tight on to stout teak wood or oak troughs, each trough being from 15 to 30 inches long and 5½ inches wide, and divided into 12 or 24 cells by partitions of slate. The plates, connected together by copper slips, were placed across the slate partitions, and the cells were filled to within an inch of the top with siliceous sand, which was then saturated with a mixture of one part sulphuric acid and fifteen parts of water.

THE GRAPHITE BATTERY.

This battery is used in England to some extent for ringing signal bells on the railways, and consists of platinized gas carbon and amalgamated zinc plates plunged in dilute sulphuric acid. The carbon plates are platinized by the electrotype process, using a straw colored solution of platinum, with a battery of 4 plates. The tops of the plates are electrotyped with copper, which is afterwards tinned, and the connecting straps are riveted to the plates with tinned rivets, and then soldered. The electrotyping of the top of the plate is accomplished by placing the part to be covered with copper in a saturated solution of blue vitriol, and connecting it to the — pole of a single Daniell cell, the + pole of which is connected with a copper plate in the same solution with the carbon, but not touching it.

If the jar is considerably deeper than the plates, so that the solution of sulphate of zinc can fall to the bottom as it forms, leaving the lighter acid at the top, the battery will last for a long time. It is not, however, suitable for a continuous current.

SECONDARY BATTERIES, OR LIQUID CONDENSERS.

Grove's gas battery, which is intended more for instruction than use, is made as follows: Into the two outer necks of a three necked bottle two glass tubes are fitted, each of which is open below, and a platinum wire enters them hermetically above, to which a long strip of platinum is soldered, extending nearly to the bottom of the tube. Little cups, containing mercury, are attached to the upper end of these wires. The bottle is filled with slightly acidulated water, and the poles of a galvanic battery are placed in the little cups. Water is thereby decomposed: oxygen forms in the one tube and hydrogen in the other. When the battery wires are removed no change takes place till metallic connection is established between the cups, and the oxygen and hydrogen gradually disappear, attended by an electric current which passes from the oxygen to the hydrogen. When several of these are put together in a battery, the connection being always oxygen to hydrogen, they can decompose water. The most important fact illustrated by this battery is that the oxygen and hydrogen, liberated by galvanic agency, when left to themselves, produce a current the opposite to that which separated them. When the poles of the decomposing battery are in the mercury cups hydrogen is given off at —, and oxygen at the + pole; and as opposite electricities attract, it is manifest that the hydrogen in this action is +, and the oxygen —. When the two gases form, by means of the platinum plates, a galvanic pair by themselves, the current must proceed, as in all cases, from the + to the — within the liquid, and the reverse way between the poles; but this is the opposite of the direction of the original current.

It is, therefore, manifest that where oxygen or hydrogen is set free at any point in a galvanic circuit, they will tend to send a counter current. This tendency is called galvanic polarization. This accounts for the fact that no single galvanic pair can decompose water, as the force generated is no greater than the force of the counter current that would be produced by the liberated gases. Even two cells produce an insignificant effect.

Galvanic polarization also accounts for the sudden falling off in strength in all galvanic couples where hydrogen is set free at the negative plate. The bubbles of the gas adhering to the plate, not only lessen the surface of contact between the plate and the liquid, but exert an electro-motive force contrary to that of the pair, and this goes on increasing until the action becomes greatly reduced

Lead, or any other metal having but a slight affinity for oxygen, may be used instead of platinum for secondary batteries. A number of plates of thin sheet lead are arranged in series as a battery in cells, filled with dilute sulphuric acid. When a current from another battery passes through it water is decomposed, its oxygen forming peroxide of lead, and coating the plates on one side of each cell, while its hydrogen spreads over the opposite plates, polarizing the lead plates and forming a battery of lead with hydrogen, and lead with peroxide of lead.

A zinc-carbon battery constructed upon this principle was formerly used in London for distributing time signals, but has been superseded by the Leclanché.

THE EARTH BATTERY.

Gauss, in repeating Steinheil's experiment of conveying the galvanic current back through the earth on the Göttingen circuit, provided the termini of the wire at one of the stations with a copper plate, and at the other station with a zinc plate. When these ends were buried in the damp earth a pretty strong galvanic current passed through the line. Such a combination was evidently nothing more than a simple Voltaic element of large size; the moist stratum of earth—3,000 feet thick—between the metallic plates took the place of the felt disc.

Bain subsequently devised a similar arrangement for obtaining a durable and constant current. By burying a zinc and copper plate in the earth, where there was continual moisture, and connecting them through an insulated wire, he obtained a current of sufficient strength to work his telegraph. By a similar arrange-

ment both Bain and Weare operated their electric clocks. An earth battery of this character will produce a current of small electro-motive force until one of the metals become oxidized, which experience shows takes place very slowly.

The most extended use of the earth battery was made by Steinheil on the telegraph line erected by him along the railroad from Munich to Nanhofen in 1846, a distance of twenty miles.

The metallic plate in Munich was a sheet of copper of 120 square feet surface, and the metallic plate in Nanhofen a sheet of zinc of the same size. Both metallic plates were placed horizontally in water and connected by a copper wire insulated on poles through the air. This arrangement furnished a continuous galvanic current of sufficient strength to work the electro-magnets used by Steinheil, which, however, required but little power. The earth battery does not possess sufficient electro-motive force to work the ordinary Morse or dial telegraph.

ZAMBONI'S DRY PILE.

This consists of several hundreds, and sometimes thousands of discs of paper tinned on one side, and covered with binoxide of manganese on the other, put together consecutively, as in Volta's pile, and placed under pressure in an insulating glass tube closed with brass ends, which serve as the poles. The electric tension of this arrangement is considerable, but the strength of the current that passes when the poles are joined is next to nothing. The most important application of the dry pile is in the construction of a very delicate electrometer, which is named after its inventor, Bohnenberger's electrometer.

THE ALUM BATTERY.

The alum battery is well designed for operating bells on telegraph lines where, in a state of rest, the line is without any current—the battery being inserted only when the bells are to be rung—because even when inserted in the line 50 to 60 times

a day for this purpose, it may stand for half a year without being taken to pieces.

The battery consists of zinc and copper without porous cups, and is filled with a concentrated solution of alum, composed of 6 pounds of alum to 12 parts of water. In the beginning the glasses are only a little more than half filled, and then every five to six days a little is added to it, so that the fluid in the glasses ascends a little more. Amalgamation of the zinc disks is not required. When the bells, notwithstanding the addition of the fluid, cannot be made to strike, the elements require to be taken entirely to pieces, the zinc well scraped, glass and copper cleansed, and finally everything again put up in due order.

AMALGAMATION.

In all constant batteries, except the Daniell and its modifications, amalgamated zinc is used as a positive metal—that is, zinc covered with mercury, as it resists the attack of sulphuric acid a great deal better than unamalgamated zinc, and is, besides, more electro-positive than the latter. The zinc of commerce, moreover, is never pure, but is more or less mixed with iron, lead, cadmium or manganese, which is not dissolved in the circuit by the sulphuric acid, and hence adheres to the zinc cylinder as a hard crust, and soon weakens the electric current unless removed. Coating the zinc with mercury causes, in addition to the above mentioned advantages, these impurities to be easily removed.

The amalgamation of the zinc is very easily accomplished by dipping the zinc in a vessel filled with mercury, after having first cleaned the zinc by dipping it in a solution of sulphuric acid and water and rubbing its surface with a brush. The zinc cylinder may be dipped in a deep vessel containing mercury and muriatic acid. The following method is also recommended: Six ounces mercury are dissolved in 30 ounces aqua regia (a mixture of 7½ ounces nitric acid and 22½ ounces muriatic acid) after careful heating, and when dissolved 30 ounces muriatic acid are added thereto. If the zinc is dipped in this fluid for a few seconds it

will be completely amalgamated, even if much corroded. This plan is easy, safe, and inexpensive. The quantity of chloride of mercury above mentioned will amalgamate from 150 to 200 zincs.

Bunsen's or Grove's batteries may be amalgamated by simply pouring a small quantity of mercury into each cell containing the zinc, when the latter will remain coated with mercury as long as the supply lasts without further attention.

ELECTRO-MOTIVE FORCES OF VARIOUS ELEMENTS.

In the preceding chapter the electro-motive forces of the several previously described elements are given in terms of the British Association unit of electro-motive force, or volt. The electro-motive forces of the different elements described in this chapter are as follows: Smee, when not in action, 1.090 volts; when in action, 0.482 volts; Leclanché, 1.481 volts; Marié-Davy's quicksilver element, 1.524 volts; Marié-Davy's sulphate of lead, 0.98 volt. The Sand, Graphite, Alum and Earth elements are about the same as the Smee when in action. The electro-motive forces of the various elements do not, of course, give us the maximum current that can be got from each, for to determine that, the size of the plates, their nearness, and the liquid resistance within the cell must be also taken into account.

The electro-motive force of several of the batteries, when connected on short circuit, and especially the Smee and Sand batteries, will fall off considerably, owing to the formation of hydrogen on the negative plate. The Grove, Daniell and Gravity batteries do not so fall off, because the hydrogen is reduced by the nitric acid in the one case, and by the oxygen in the other.

The internal resistance of the Grove cell is very small, usually below half an ohm for a pint cell; Daniell, from 3 to 5 ohms; the Gravity from 2 to 4 ohms; and the Smee and Leclanché about one, varying greatly with the greater or less deposition of hydrogen. The electro-motive force of batteries is, within certain limits, very variable, depending on a variety of undetermined causes, but that of the various forms of sulphate of copper is the most constant.

CHAPTER X.

COMBINATION OF GALVANIC ELEMENTS INTO BATTERIES.

THE force of a battery, sometimes called the tension of the current, is the power which it has to transmit a current against resistance, such as that offered by a bad, long, or thin conductor, and is designated as its electro-motive force. The unit of electro-motive force is called a volt, and does not differ materially from that of a Daniell cell. The unit of resistance to the passage of an electric current is called an ohm, and is about equal to that of a cylindrical wire of pure copper, one twentieth of an inch in diameter and two hundred and fifty feet in length (No. 18 Birmingham wire gauge): or of 830 feet of No. 9 iron wire (.155 of an inch diameter) of the average quality. The unit of current is called a farad, and is equivalent to the quantity of electricity flowing per second in a circuit having an electro-motive force of one volt, and a resistance of one ohm. The quantity of electricity passing in a current, or the strength of the current, is estimated by the power of the current to deflect the magnetic needle, by the chemical decomposition it effects, or by the temperature it raises a wire of given thickness and material. The strength of the current must not be confounded with the strength of the element or battery which produces it. A battery of one hundred cells has one hundred times the electro-motive force of a single cell of the same kind, yet in certain circumstances the one cell will produce as strong a current as the one hundred. For example, suppose a single cell, having an electro-motive force of one volt and a resistance between the plates inside of the cell of one ohm, be connected in circuit by an external wire with no appreciable resistance, then the quantity of electricity flowing in the circuit per second, or the strength of the current, would be one farad. If, now, a battery consisting

of one hundred similar cells, having a total internal resistance of one hundred ohms, be connected in circuit by an external wire with no appreciable resistance, then the strength of current, or quantity of electricity flowing in the circuit per second would be, as in the former case, one farad.

The term quantity has the same meaning when applied to electricity that it has when applied to any other force or substance. The greatest quantity of current which a given galvanic element can produce is proportional to its surface. By doubling the size of the plates the amount of current is doubled, provided the connecting wire offers no appreciable resistance; and the quantity is not increased by increasing the number of cells. The electromotive force of a battery, on the contrary, is not affected by the size of the plates, but by the number of cells in the combination—an element of the size of a cherry stone possessing as great an electro-motive force as one composed of the same substances holding a gallon.

The quantity of current flowing from a battery over a conductor is ascertained by dividing its electro-motive force by the resistance of the circuit, including the battery—the quotient representing the quantity or strength of the current flowing in the circuit.

If a Daniell and Grove cell were so constructed as to produce the same maximum current in a closing wire of the same resistance, and the interpolar connection be then made by a long, thin wire, the current which each gives will fall off, but that of the Daniell element will decrease more than the Grove. This would be generally expressed by saying that both elements were of the same quantity but of different potential, the Grove element having a greater electro-motive force would give a stronger current upon a wire of greater resistance. This will be apparent by applying the rule given above. For example, suppose the Grove element had an electro-motive force of two volts and a resistance of one and a half ohms, and its poles were joined by a wire having a resistance of half an ohm, making the whole resistance of the circuit two ohms, then the

strength of current upon the wire would be one farad. Now, if the Daniell element had an electro-motive force of one volt and a resistance of half an ohm, and its poles were joined by a wire having a resistance of half an ohm, the strength of current upon the wire would be one farad, as in the other case; but if the Grove element were connected in circuit with a wire having three and a half ohms resistance, which, with its own internal resistance, would make a total resistance of five ohms, then the strength of current upon the wire would be 0.4 (four tenths) of a farad; while if the Daniell element were connected in circuit with a wire of the same resistance the strength of current in the circuit would be only 0.25 (two and a half tenths) of a farad.

The arrangement of the elements into batteries varies according to the purpose they have to serve. A maximum magnetic effect may be obtained from a given number of elements, if they be so arranged that the resistance in the battery is equal to the resistance in the closing wire. A given number of elements can be combined in several different ways For instance, eight elements can be arranged in four different ways, as shown in figs. 5', 55, 56 and 57. Which one of these combinations should be selected, in a given case, depends upon the resistance to conduction of the circuit. That combination must be taken, the resistance of which is nearest to that of the given circuit.

In fig. 54 the elements are connected, one after the o her, into a battery containing eight successive pairs of plates, and the current has to pass in succession through each of the eight elements.

Fig. 55 represents the reverse, all the zinc cylinders being connected together to form one zinc pole, and all the copper cylinders connected together to form one copper pole, the whole forming a single element of eightfold surface In this case, the elements are connected side by side for the production of the largest quantity of current through a circuit of the least resistance. In the former case, the elements were connected for the purpose of producing the greatest quantity of current through a circuit of the most resistance.

Between these two cases there are the two others, represented by figs. 56 and 57. In fig. 56 the four elements, 1, 2, 3 and 4, one after another, are connected as one battery, as are also the elements 5, 6, 7 and 8. The corresponding poles of both batteries are connected with each other, and, hence, this battery represents a voltaic pile of four pairs of plates, of which each has double the surface of the pair of plates shown in fig. 54.

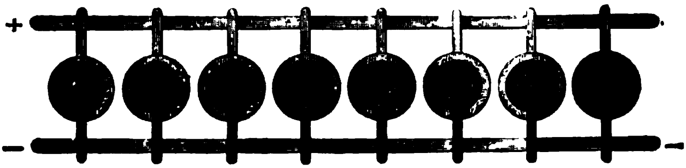
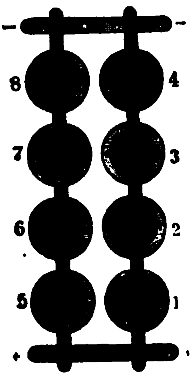


Fig. 55.



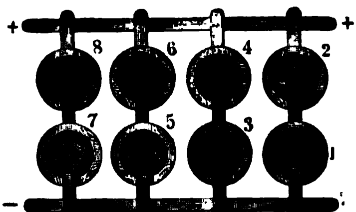


Fig. 54. *Fig.* 56. *Fig.* 57.

Fig. 57 represents the connections in which each two elements (1 and 2, 3 and 4, 5 and 6, 7 and 8) form a battery of two pairs of plates whose surface is four times as large as in the pairs shown in fig. 54. Supposing the resistance of an element to be 4 ohms, the resistance of battery shown in fig. 54 would be 32 ohms; in fig. 56, 8 ohms; in fig. 57, 2 ohms; and in fig. 55, 0·5 of an ohm. Considering the different combination of the 8

elements represented, it is seen that, as the pile is shortened, it becomes broad in the same proportion; and hence, by making the pile one half as long and twice as broad, the resistance is reduced to one fourth of its former amount.

Now, in determining which combination of the above elements would be the most suitable for any given circuit, reference must be had to the resistance of the circuit; and if the greatest magnetic effect is desired upon each, the resistance of the closing wire, including the electro-magnet, must exactly equal the resistance of the battery.

DIFFERENCE BETWEEN FRICTIONAL AND VOLTAIC ELECTRICITY.

The electricity of the voltaic battery differs from that of the electrical machine in its low tension; in its large quantity, and in its continuous current.

A battery of 50 cells produces but a slight divergence in the gold leaf electrometer, and through ordinary air the spark will not pass a distance of more than one or two hundredths of an inch. A voltaic battery with 1,000 pairs of plates will not exhibit electric repulsion so decidedly as a small stick of sealing wax rubbed with fur.

If we measure the quantity of electricity developed in a machine by the effect it will produce in decomposing water, then a simple voltaic element which might be contained in a common thimble develops a greater quantity of electricity than a gigantic electric machine. Faraday has estimated that a zinc wire $\frac{1}{18}$ of an inch in diameter, and immersed to the depth of $\frac{5}{8}$ of an inch in diluted acid, in three seconds of time yielded as great a quantity of electricity as a Leyden battery charged by 30 turns of a plate glass machine 50 inches in diameter.

An increase in the size of the plates increases the quantity but not the tension of the electricity. An increase in the number of the plates increases the tension of the electricity but not its quantity.

CHAPTER XI.

ELECTRO-MAGNETISM.

THE discovery of the relation between electricity and magnetism was an object eagerly sought for by many of the most profound naturalists of the last century, and their efforts for its attainment were stimulated by prizes and rewards offered by scientific societies. Oersted, after having tried for it many years, happily succeeded in obtaining the long desired result in the year 1819. He found that a magnetic needle balanced on its centre of gravity in the neighborhood of a wire through which an electric current is passing, takes a position which would be exactly perpendicular to the wire if no other magnetic

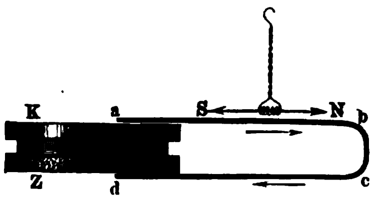


Fig. 58.

or electro-magnetic force acted on it; that end or pole of the needle which has the same magnetic quality as the north polar regions of the earth, is driven to the south if the line of current be from east to west and below the line of the needle, or if from west to east and above it. And if the point of support of the needle and the wire conveying the current be held fixed while the direction of the current is reversed, the needle is as much deflected in the opposite direction.

The simplest way to observe this phenomenon is to take either a single pair of zinc and copper plates, Z and K, fig. 58, separated by a moist conductor, or any other galvanic battery closed

by a wire *a*, *b*, *c*, *d*, over which a magnetic needle, S, N, is freely suspended. As soon as the + current begins to flow in the direction K, *a*, *b*, *c*, *d*, Z, the north pole of the needle is deflected to the right, and when the direction of the current is reversed, to the left. If the needle is suspended under the wire instead of over it the deflections are reversed.

The manner in which a needle should turn when influenced by a current is easily kept in mind by Ampere's rule : Suppose the diminutive figure of a man be placed in the circuit, so that the current shall enter by his feet and leave by his head, when he faces the needle its north pole always turns to his left. If the current enters by his head, under the same conditions, the north pole of the needle will turn to his right.

In the accompanying illustrations the figure of the man is

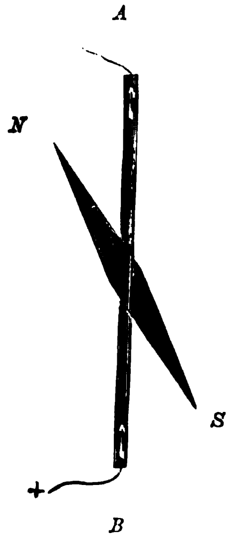


Fig. 59.

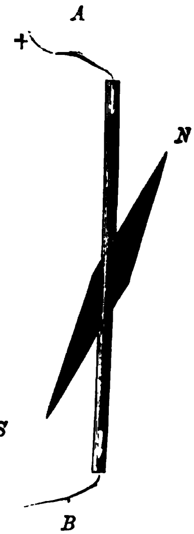


Fig. 60.

represented by the wire A, B, and the needle by N, S. In figure 59 the current enters by his feet, and in figure 60 by his head. If the needle were placed on the other side of the wire its deflection would be reversed.

When a magnetic needle is placed under a straight wire, through which a current passes, it deflects to a certain extent, and when the wire is bent so as also to pass below the needle, it deflects still more. This is easily understood from the above rule. The supposed figure has to look down to the needle when in the upper wire, and to look up to it in the lower wire, so that his left hand is turned in different ways in the two positions.

The current in the upper and lower wire moves in opposite directions, thus changing in the same way as the figure, and the deflection caused by both wires is in the same direction. By thus doubling the wire the deflecting force is doubled. If the wire be carried a second time around the needle the effect will be again doubled, and by a still further increase in the number of turns a corresponding increase in force will be obtained.

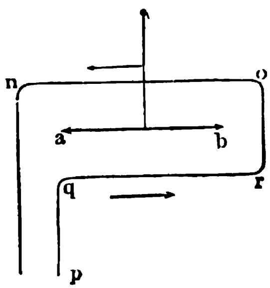


Fig. 61.

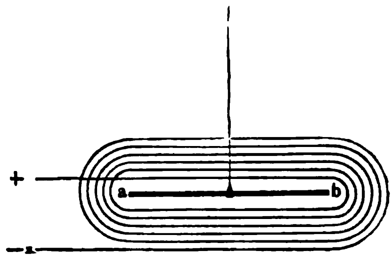


Fig. 62.

In fig. 61 *b* is the north, and *a* the south end of a magnetic needle which is suspended between the wire *n*, *o*, *r*, *q*, *p*, bent to a rectangle. When the + current appears at *p* and passes through the wire in the direction of the arrow, the north end of the needle *b* is deflected to the left, both by the action of the current above the needle and under it, and hence the deflecting power is double what it would be if a single wire acted over or under it merely.

In fig. 62 the closing wire is wound six times in the same direction as the first wire *q*, *r*, *o*, *n*, around the needle, and the deviating action of the current on the needle is twelve times greater than in a single rectilinear wire, so that such an arrange-

ment multiplies the action of the current on a magnetic needle.

Thus a very feeble current, whose action would be scarcely sensible if the wire by which it is transmitted made but one convolution, is able to exert a very marked action when the number of convolutions becomes considerable. This is done by insulating the wire so that the different convolutions may be juxtaposed and superposed, without causing a direct metallic communication from one convolution to another, thus compelling the current to traverse its entire length.

THE GALVANOMETER.

Such an apparatus, which was original with Schweigger, is called a galvanometer multiplier, and affords the most convenient and accurate means for measuring the strength of a galvanic current which has ever been devised.

Fig. 63.

Galvanometers are made in many forms and for various purposes. In some cases the needle hangs vertically, and is kept in

its normal position by gravitation, the lower end being heavier than the upper; while in other cases the needle is poised in a

Fig. 64.

horizontal position, like that of a mariner's compass, fig. 63, or suspended by means of a silk fibre, fig. 64.

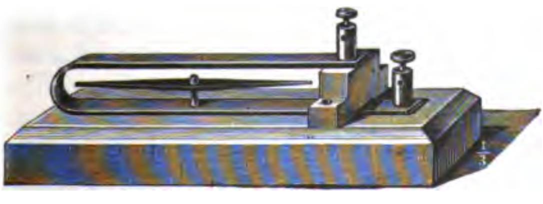


Fig. 65.

The simplest form of a galvanometer is represented in fig. 65.

and consists of a single copper wire surrounding the magnetized needle. It has no arc divided into degrees, and hence can only indicate the presence and direction of a current of considerable strength.

Fig. 66.

Fig. 66 represents a vertical galvanometer which requires no adjustment, as the north end of the inner needle is made sufficiently heavy to keep it in a vertical position ; but it is not as sensitive as the other forms, and as the force with which a current acts upon it depends on its magnetism, which is constantly decreasing, its indications vary from time to time.

In the above cut Z Z represents the needle, whose angle of deflection is proportional to the quantity of electricity flowing through the coils, the direction in which it moves indicating the direction of the current. The scale *d*, *e* is divided into two equal parts, in the centre of which is the zero point, where the upper portion of the needle rests when no current is passing through the coils; from the zero point the scale is divided to the right and left into degrees, by means of which the angle of deflection of the needle can be read.

In a horizontal galvanometer the needle is kept in its place by its tendency to point north and south through the action of the earth's magnetism, and therefore the feebler the magnetism of the needle the less resistance will it offer to being moved by the current, while on the other hand the current acts with

less force on a feeble magnet, and thus the instrument remains constant. In constructing a horizontal galvanometer (fig. 67)

Fig. 67.

the wire is coiled round a wooden or metal frame, so as to leave between its lower and upper surface the smallest possible space, in the interior of which the magnetized needle *s*, *n* is suspended. The angle or number of degrees through which the magnetized needle is moved is indicated upon the scale *e*, *d* by the pointer *z*, and shows the quantity of electricity passing through the coils, while the direction in which it moves indicates the direction of the current.

In order to increase the sensibility of the galvanometer, Professor Cummings suggested the idea of neutralizing the directive force of terrestial magnetism by employing two needles, as nearly alike as possible, placed parallel to each other, with their poles in opposite directions, and suspended so as to move freely by a thread without torsion. Magnets so arranged have little tendency to place themselves in the magnetic meridian, as the one would move in a contrary direction to the other. If they were of exactly the same power they would remain indifferently in any position. As they cannot, however, be so accurately poised as this, they always take up a fixed position, arising from the one being somewhat stronger than the other. Such a compound needle is called astatic, as it stands apart from the directing magnetic influence of the earth.

If an astatic needle be placed in a coil, so that the lower needle be within the coil and the upper one above it, its deflection will be greater than a single needle, because the power which keeps the needle in its fixed position is small and the needle is more

easily influenced; and also because the force of the current is exerted in the same direction on two needles instead of one.

An astatic needle so placed in a coil constitutes an astatic galvanometer. The upper needle moves on a graduated circle, from which the number of degrees that the needle deflects may be read off.

When deflection of the needle takes place, the different portions of the coil are differently situated with respect to it from what they are at zero, and therefore the deflecting force of the coil differs with the position of the needle, so that the deflection caused by different currents are not proportional to the angles of deviation above 20°.

Galvanometers may be made of almost any required sensitiveness for weak currents, by making their needle system sufficiently astatic.

The astatic condition of a pair of needles is measured by the time it occupies in making an oscillation across the magnetic meridian. Matteuci had a pair which took seventy seconds to make a single oscillation; but from five to ten seconds is a very convenient degree of directive force to obtain for the measurement of high resistances by weak currents, otherwise the zero of the needle system is liable to be changed by trifling disturbances over which the operator has no control.

There is another circumstance which prevents the angle of deviation from being proportional to the quantity of current passing through the galvanometer, viz., that the directive force of the globe, which, by tending to bring back the needles into the magnetic meridian, produces equilibrium with the force of the current that moves from it, is proportional, not to the angles but to the sines of the angles of deviation; and that from about 20° the difference between the arc and its sine becomes too considerable to permit their being taken indifferently for each other.

In the sine galvanometer or in the tangent galvanometer these sources of error are avoided. The sine galvanometer is composed; first, of a vertical metallic ring G, H (fig. 68), having

upon its circumference a groove sufficiently deep and wide to contain the insulated wire which is wound round the circle and constitutes the coil; second, of a magnetized needle I, poised upon a pivot in the middle of the circle E, D, and which receives the influence of the multiplicator; third, of a divided circle A, B, maintained in a perfectly horizontal position, and over which the movable transom C carries the multiplicator G, H and its needle. A system of levels and binding screws permits the establishment of the rigorous horizontal of the circle A, B. The instrument is placed north and south, and when the circle

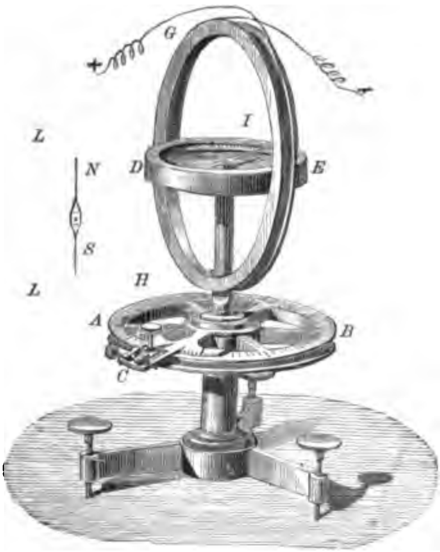


Fig. 68.

G, H, and the magnetic needle are both in the plane of the magnetic meridian, the apparatus is at the zero of the division. When a current is sent through the wire which surrounds the circle G, H, the needle is deviated in proportion to the magnetic force which is induced by the current. The transom that carries the multiplier is then turned until it is brought again into the plane of the needle. In order to conveniently observe the exact direction of the needle a copper pointer with an index line

is fixed at right angles upon it. The needle is exactly parallel to the mean plane of the multiplier when the index line of the pointer falls beneath the wire of a lens that is fixed to the movable piece upon which the galvanometer is adjusted. When the needle is deviated by the passage of the current through the multiplier, the transom is turned until the wire of the lens coincides with the index line, and the division traced upon the fixed circle indicates the number of degrees it was necessary to turn from 0 in order to obtain this coincidence. The strength of the current is proportional to the sine of the angle measured upon the circle A, B by the movement of the alidade C.

In this apparatus the needle preserves the same position in relation to the current, which consequently acts upon it in the same manner. The extent of the deviation must depend, therefore, solely upon the quantity of the current passing through the galvanometer.

As the sensitiveness of the apparatus depends upon the number of convolutions of the conducting wire upon the circle, it can be made applicable to any strength of current by increasing or diminishing the number of convolutions.

THE ELECTRO-MAGNET.

The galvanic current not only acts on a piece of steel or iron which is already a magnet, but it converts any piece of non-magnetized steel or iron in its neighborhood into a magnet, having its poles so situated that they lie in the line along which a free magnet would place itself under the action of the current. This magnetizing action is more powerful as the iron is placed nearer the current, as the current is more powerful, and as a greater length of the current acts in the same sense on the iron. In fig. 69, C, is a bobbin, around which is rolled a long copper wire covered with silk, into the interior cavity of which is placed a bar of soft iron, A, B. At the moment that an electric current is transmitted through the wire of bobbin C, the bar, A, B becomes a magnet, and remains magnetic as long as the current continues to flow, and relapses into the neutral state the moment

that the current is interrupted. The magnetism which is developed in the bar increases with the strength of the current, and with the number of convolutions of the conducting wire, provided the diameter of the bobbin be within such limits that the action of the current remains comparatively independent of the distance of the wire from the soft iron bar. Experimental research has deduced the general law that the magnetic force developed in a soft iron bar is proportional to the product of the strength of the current by the number of turns of wire which surround the core. This is not absolutely correct in all cases, as experiment shows that for each soft iron bar, there is a maxi-

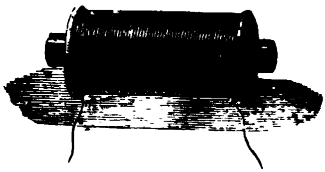


Fig. 69.

mum of magnetic intensity, which cannot be exceeded. This maximum is proportional to the diameter of the bar.

While, however, the multiplication of the number of convolutions of wire on the bobbin increases the action of the current on the soft iron bar, it diminishes the quantity of the current passing through the wire by making a considerable increase in the resistance of the circuit. Consequently there is a certain arrangement of the wire of the bobbin, which cannot be deviated from, that with a given battery, and acting in determined conditions, will communicate to a soft iron bar the maximum of magnetic intensity.

Between the limits in which the above mentioned general law is applicable, experience and the considerations deduced from the laws on voltaic currents agree in establishing the following rule:

When the resistance of the wire on the bobbin is equal to the resistance of the exterior circuit of the electro-magnet, including

that of the battery, the maximum of magnetic intensity is obtained.

The most generally useful form of electro-magnet is that usually called the horseshoe, although it is now seldom made in the precise form which its name indicates. The construction more usually adopted is shown in fig. 70, and consists of a rectangular bar, or yoke-piece of soft iron T, into which are screwed two cylindrical cores, as they are termed, A B, also of soft iron. Upon these are slipped two bobbins or spools, C C', composed of many layers of insulated wire, overspun with silk or cotton. The inner ends of the wires of the two spools are then connected together and the outer ends left free for attachment to the battery or other conductors. Thus the wire of both spools in fact forms a continuous circuit, all the convolutions passing round the soft iron in the same direction, if the lat-

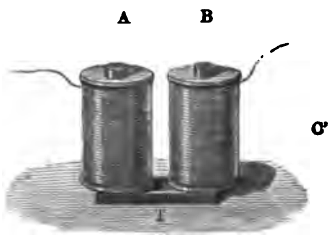


Fig. 70.

ter be considered as a continuous straight bar, although its actual form is such that the convolutions upon the two cores are apparently reverse to each other. The ends of the cores, technically termed the poles of the electro-magnet, are usually provided with flanges, in order to retain the spools in their position.

The electro-magnet is provided with an armature, which is kept just short of touching the poles, for when it is in contact, a residuum of the induced magnetism lingers in it and in the core after the current stops. It is important that the magnetism in the core should instantly and entirely cease as soon as the current is broken, and hence the iron should be of the softest kind—old Swedish iron being preferable—and the cores should not exceed four inches in length.

CHAPTER XII.

ELECTRO-MAGNETIC INDUCTION.

THE galvanic current exercises its influence not only upon a magnet, which may by this means be made to deviate from its state of rest, but also, as described in the preceding chapter, upon unmagnetized iron, which, under appropriate conditions, may be converted into a powerful magnet. For this purpose the soft iron is usually made in the form of a horseshoe, which is surrounded by heliacal coils of properly insulated copper wire wound upon it, care being taken that the coils retain the same direction as if the horseshoe were stretched out straight. When the extreme ends of the wire are connected with the poles of a galvanic battery, the iron instantly becomes magnetic, and continues in this condition as long as the current lasts. One end of the horseshoe becomes a magnetic north pole, the other a south pole. The kind of polarity depends upon the direction of the turns of the helix and upon the direction of the current in the wire.

THE AUTOMATIC CIRCUIT-BREAKER.

When the core of the electro-magnet is made of very soft iron, it receives its magnetism instantaneously when the circuit is closed, and as suddenly loses it when the circuit is broken. Advantage has been taken of this quality of the electro-magnet, both in physics and in telegraphy, to produce exceedingly rapid mechanical motions, and apparatus have been constructed which, under the influence of a galvanic current, will continuously maintain the most rapid motion by their own automatic action.

The principle upon which all these instruments are based is that of the automatic circuit-breaker, and will be easily understood by reference to fig. 71.

Over the poles of an electro-magnet *b* the armature *a* is sus-

pended by a steel spring *d*. This spring presses the armature (when it is not attracted by the electro-magnet) against an adjustable contact-screw *c*, which is connected with one of the poles of a galvanic element; the other pole of this element is connected with the coils of the electro-magnet, which are in turn connected with the metallic post *e* supporting the steel spring *d*. As soon as the circuit is closed the current flows through + *b*, *e*, *d*, *a*, *c* — passing around the electro-magnet. The armature *a* is at once attracted, whereby the contact between *a* and *c* is broken.

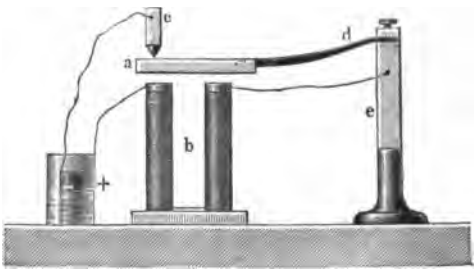


Fig. 71.

The electro-magnet *b* then again loses its magnetism, the spring *d* throws the armature *a* up towards *c*, the circuit is restored and the movement is repeated. In this way an uninterrupted series of breaks and closes of the current takes place, causing a continuous vibration of the armature of almost inconceivable rapidity.

The principle on which this operation is based may be expressed as follows: The current induces magnetism in an electro-magnet, hence in succession follow attraction of the armature, breaking of the circuit, falling off of the armature, closing of the circuit and reëstablishment of the current, and so on indefinitely.

THE MOST IMPORTANT PHENOMENA AND LAWS OF GALVANIC INDUCTION.

It was known at a very early period that a magnet is capable of magnetizing a piece of iron which is brought near it, though

not in contact with it; and it was also known that the electricity developed from the electrical machine electrifies any body in the neighborhood of the conductor by action from a distance. To these phenomena Faraday added, in 1830, the important discovery that a galvanic current is able to induce other galvanic currents in wires which are in its vicinity, without actual contact with them. The process of action by which these additional currents are produced by a current already present is called electro-dynamic or galvanic induction. The currents generated are called induced or secondary currents; the generating current, originating in the battery, is called the main, or, more frequently, the primary current.

The principal law of galvanic induction is the following: If a closed circuit is in proximity to a wire or a conductor which is

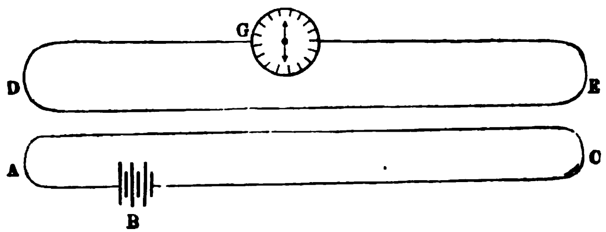


Fig. 72.

in connection with a galvanic battery, then, at the moment when a current arises or ceases in the primary wire, a secondary current of momentary duration originates in the auxiliary wire. This secondary current, produced by the primary current in the adjacent wire, is termed the induced current. To illustrate this phenomenon, let us suppose B, fig. 72, to be a galvanic battery, and A C the wire which connects the poles of this battery; in the vicinity of, and parallel to which, is the wire D E, whose extreme ends are connected to a galvanometer, G, capable of indicating the presence of a galvanic current. As the wire D E is not connected with the galvanic battery no current circulates through it, and the magnetic needle of the galvanometer G remains at rest. Now, as soon as the circuit of the battery B is

closed, and a current traverses the wire A C, a current also originates in the second wire D E, whose presence is immediately indicated by the galvanometer G, and whose direction is opposite to that of the primary current. If we suppose the current in the main wire to flow from A toward C, then the induced current in the auxiliary wire will flow from E toward D.

The induced current is almost instantaneous, continuing but a moment and then disappearing, although the primary current of the battery B continues to flow in the wire A C. The moment the circuit of the battery B is closed, the needle of instrument G is suddenly deflected, indicating by its movement the formation of the induced current, when it returns immediately to a state of rest, and remains thus during the continuance of the current in the wire A C.

As soon, however, as the circuit of the battery B is opened an induced current appears in the secondary wire D E simultaneously with the disappearance of the main current. This is also of momentary duration, and traverses the wire in the same direction as the disappearing main current. As we have seen, if the battery current circulates in the direction from A to C, then the induced current which originates in wire D E, when circuit of the battery is opened, will be in the same direction as the main current, or from D to E, while the secondary current, which arises when the primary current is closed, is in the opposite direction, or from E to D.

The passive condition of the wire while thus under induction has been described by Faraday as electro-tonic. An electric throb, so to speak, marks the setting in of this state, and another its vanishing, the former in the opposite direction to that of the inducing current, and the latter in the same direction. If the primary wire A C be movable, so that it can be suddenly brought near to and withdrawn from the secondary D E while the battery current passes steadily, currents are induced as in the former case, the approach of the wire being marked by an inverse current and its withdrawal by a direct one. As long, however, as the primary wire remains in any one position, all

evidence of electricity in the secondary wire disappears; but if in this position the strength of the primary current should be increased or diminished, momentary currents in the secondary wire would again mark the changes in the primary, the increase causing an inverse and the decrease a direct current. Hence, we conclude that a current which begins, a current which approaches, or a current which increases in strength, induces an inverse momentary current in a neighboring conducting circuit; and that a current which stops, a current which retires, or a current which decreases in strength, induces a direct momentary current in a neighboring circuit.

The intensity of the induced current is proportional to the strength of the primary current, or the strength of the battery; moreover, it depends upon the distance of the secondary from the primary wire, and upon the length of wire subjected to the inductive action. Now, as the aggregate inductive action of the

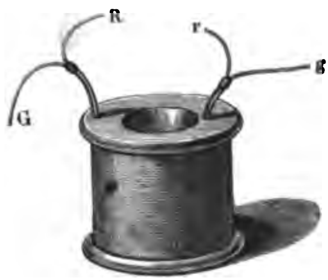


Fig. 73.

main wire A C consists of the total of lesser actions, such as the single element of A C exercises upon the neighboring portions of the wire D E, so the induced current in D E increases in proportion to the number of such portions of A C which act inductively on the secondary wire. Hence, in general, the effect increases with the length of both wires.

The latter consideration serves as a guide in constructing apparatus by means of which powerful induction currents are to be produced. These consist, as shown in fig. 73, of two dis-

tinct wires brought close together, which must not, however, be allowed to come into conducting contact. For this purpose the wires are very carefully overspun with silk, which insulates them from each other. They are then wound for a great length in the same direction close together on a wooden or pasteboard bobbin. The primary wire (for instance R *r*, through which the battery current is conducted), is much thicker than the secondary wire forming the induction coil. The fine wire G *g* is the secondary, and the heavier the primary or main wire.

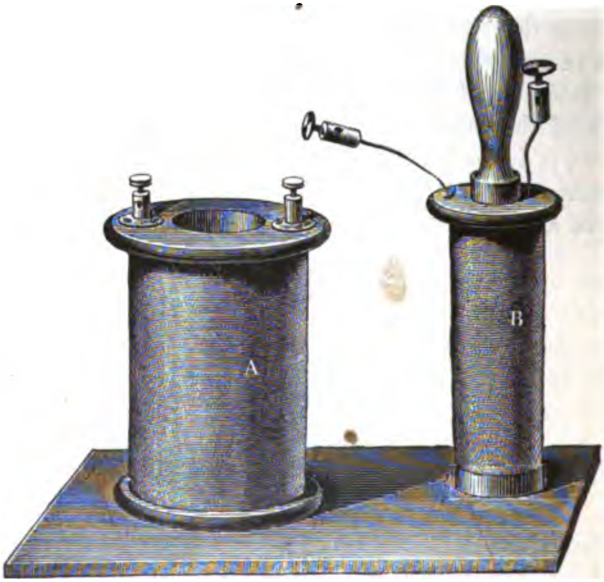


Fig. 74.

In some instances, as shown in Fig. 74, each of the two wires is wound, well insulated, upon a peculiar wooden bobbin, cylindrically grooved, and so arranged that the coil B of the main wire may be placed inside of the hollow coil A, consisting of thin wire. In all cases the ends of the thick wire are connected with the battery, while the ends of the thin wire either to each other, or to the parts through which the induced current is to be conducted.

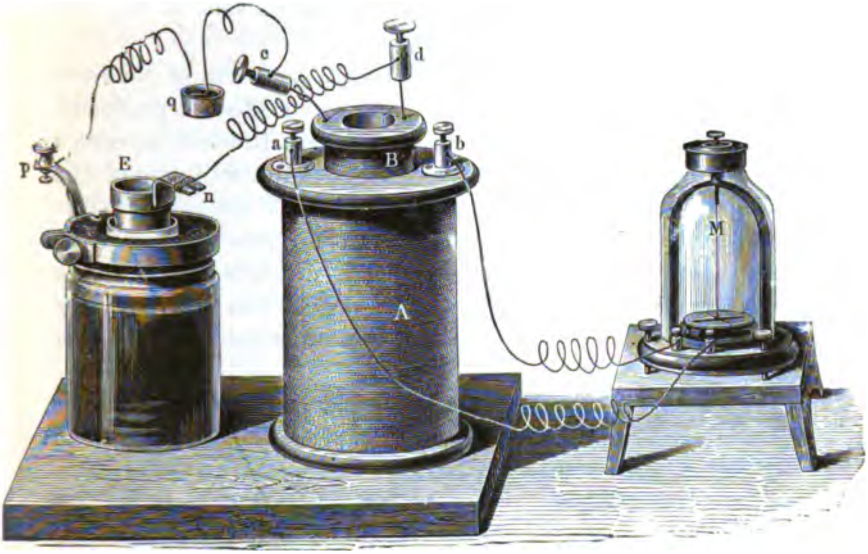


Fig. 75.

Fig. 75 shows the construction of these parts. A is the induction coil, consisting of a long, fine wire; B is the primary or inducing coil of thick wire, E the battery, and M the galvanometer. The extreme ends *a b* of the coil A are connected with the galvanometer, and the ends *c d* of the thick wire, by means of a mercury cup *q*, with the poles *p n* of the battery. When in a state of rest the needle of the galvanometer indicates that there is no current circulating in the coil A. When, however, the circuit is closed at *q*, then the movement of the needle at M indicates that the coil is being traversed by a current which is in an opposite direction to the current of the coil B. When the battery circuit is opened the needle again moves to nearly an equal distance in the opposite direction.

As long as a current traverses the wire B the needle of the galvanometer remains at rest, although any sudden increase in it will induce a current of opposite direction in the secondary wire A; on the contrary, any sudden decrease of the current

strength in the main wire causes an induced current in the secondary wire in the same direction.

If the main or primary wire be brought nearer to or removed further from the secondary wire, the same effect is produced. That is to say, if the thick wire of the coil B, while traversed by a current, is brought suddenly nearer to the thin wire of the coil A ; or, what amounts to the same thing, if the coil B, while traversed by a current, is suddenly inserted into the coil A, an induced current originates in the coil B, which is *opposite* to the main current. By the rapid withdrawing of one coil from the other another induced current is generated, which is in the *same* direction as the battery current.

As we have seen, the number of induced currents depends entirely upon the number of times the primary circuit is opened and closed, and it therefore becomes necessary, in the arrangement of induction apparatus, to provide means by which the battery current may be opened and closed with the utmost possible rapidity and certainty.

This operation, simple as it may seem, cannot be successfully performed by hand. Hence, this function is transferred to the current itself, by the employment of an automatic circuit breaker.

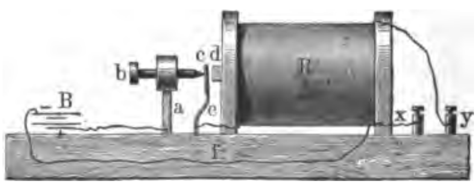


Fig. 76.

Fig. 76 represents such an arrangement with a spring breakpiece. R is the induction coil, composed of thick and thin wire; it has an opening in its centre, which is filled up by cylinder *d* of soft iron, or with a bundle of wires of the same material, which, in connection with the coil of thick wire, forms an electromagnet. The iron core *d* projects somewhat from the coil ; op-

posite to it is placed a small iron plate or armature *c*, which is attached to a metallic spring *e*, which, when in a state of rest, presses the armature against the metallic contact screw *b*, supported by the brass pillar *a*. This screw may be adjusted forward or backward, so as to make the plate *c* approach the iron core, more or less, according to the strength of the current. One end of the thick wire is attached to the spring *e*, and is wound around coil R, serving to conduct the current of the battery B around the coil; the other end of the wire *f* proceeds to one of the poles of battery B, while its other pole is connected to the screw post *a*.

As soon as the battery B is connected, as represented in the figure, the current proceeds from the + pole towards *a*, through the screw *b* to the plate *c* and spring *e* to the thick wire of coil R, and thence through the coil, and finally out through the wire *f* to the — pole of the battery.

The current which circulates around coil R causes the inner core of soft iron to become magnetic; the pole *d*, therefore, attracts the small iron plate *c*, and separates it from the screw *b*. The current which is passing over *b* to *c* is thus interrupted; the magnetism disappears from the iron core *d*, the light armature *c* is no longer attracted, and owing to the elasticity of its support *e*, springs back against the contact screw. When the contact is reëstablished, the current flows again; the core *d* becomes magnetic, and attracts *c*, and the current is again interrupted. In this way the play of the automatic circuit-breaker continues indefinitely, the current in the primary coil being alternately established and broken. Hence there originates in the neighboring thin wire, whose extreme ends are seen at *x y*, a series of induced currents, which may be conducted beyond the terminals *x y* by means of conductors connected thereto, which may be used at pleasure.

THE EXTRA CURRENT.

It is not necessary, in order to generate an induced current, that two distinct wires should be employed. Experiment proves

that inductive action also takes place between separate con volutions of the same wire, when the latter is wound up in the form of a heliacal coil. At the instant the battery is closed through such a coil, an induced current is set up in the same wire, which opposes and therefore weakens the originating current. So also upon breaking the battery current, an induced current is again set up in the coil, this time in the same direction as the battery current, and adding to its strength. The longer the wire of the coil and the greater the number of its convolutions, the more powerful will be the extra current. Induced currents generated in this manner, in the same wire in which the primary current flows, are termed extra currents, or counter currents. It is on account of this extra current that the shock which the human body experiences when the battery circuit is closed, is far less intense than that which is felt at the breaking of the same circuit. One of the principal reasons of the lack of success which has hitherto attended all attempts to construct motors by the use of large electro-magnets, is this action of the extra current upon the primary current from the battery, which interferes seriously with the rapid charging and discharging of the magnets.

In consequence of the appearance of the extra current in opposition to the primary or battery current, at the moment of closing the circuit, the battery current does not attain its full strength, either in a heliacal coil or in a very long straight wire, at the first instant of closing, nor does the current disappear instantaneously when the circuit is broken. That is to say, a gradual increase of the current takes place upon the closing of the circuit, and it is not until after the lapse of one fifth to one sixth of a second that it attains its maximum strength. When, as is almost always the case, the helices or coils surrounding the iron core of an electro-magnet are included in the circuit, this time is lengthened to as much as one half or three fourths of a second, which must elapse before the current, and consequently the magnetism of the iron cores can attain its maximum strength. This is one of the reasons why it is not possible to telegraph

with anything like the same rapidity on long lines as on shorter ones, and also explains the fact that in all electro-magnetic motors it is impossible to increase the speed beyond a certain limit.

Like the ordinary induced currents, the extra currents possess all the qualities of those derived from the galvanic battery. They may be made to develop light and heat; to create powerful electro-magnets, to decompose water and other chemical compounds; and especially to produce very powerful physiological effects. The chemical effects of a current are always in proportion to its effect upon the galvanometer. This, however, is not the case with its physiological effects. An induced current which shows but a very slight effect upon the galvanometer, is often capable of producing very powerful shocks in the muscles of the human body. For this reason, when the physiological effect of any given current has been augmented, the electro-magnetic effects of the same current are not necessarily greater.

The phenomenon of the extra current was first observed by Prof. Henry in 1832. It was afterwards made the subject of investigation by Faraday in 1834, and by Henry in 1835.

THE PHENOMENA OF TENSION OR POTENTIAL IN THE INDUCTION COIL.

The electricity produced by the frictional machine accumulates upon the surface of a metallic globe or cylinder, and remains at rest, or, as it is termed, in a static condition, it being assumed that this conductor is perfectly insulated. In this case the electric density depends upon the extent of the surface upon which a certain quantity of electricity is required to distribute itself. The smaller this surface is, in proportion to a certain quantity of electricity, the greater will be the density of the latter. Furthermore, as the separate particles of this electricity, if we may so express it, repel each other, and only exercise an attraction for the opposite kind of electricity; therefore there appears, simultaneously with the accumulation of electricity upon the surface of any body, a tension or potential, which necessarily increases or decreases according to the electric density. The

tendency of this accumulated electricity to reunite with the opposite electricity increases in proportion to the tension, aud this may at length become so great, as to be able to overcome a considerable extent of non-conductor, such for instance, as the air, in order to reëstablish the equilibrium. The electric machine, therefore, produces static electricity. So, also, the Leyden Jar, when charged, contains static electricity, and in the same manner lightning originates from the static electricity contained in the clouds.

When, on the other hand, the accumulated electricity in a body is not confined by non-conductors, but is permitted to reunite with the opposite electricity by means of good conductors, then it passes off, and the body either returns to its natural non-electric condition, or when, as in the case of the galvanic battery, it carries within itself the source of a continually recurring electrical disturbance, a constant current of electricity is maintained. In this case the electricity is said to be in a dynamic condition, as distinguished from electricity in a static condition. An electric machine which is kept in constant rotation, and which has its rubbers connected with the prime conductor, is one example of this, and a galvanic battery having its poles connected by a conducting wire is another. In both cases the electricity which is generated flows freely through the connecting wire, but possesses a tension almost infinitely small. Dynamic electricity, however, possesses quantity, as well as tension or potential. By the former is meant the amount of electricity which passes a given cross-section of the conductor in a given time, while the potential, on the other hand, is analogous to the tension of static electricity, and depends upon the relative proportion between a given quantity of electricity and the sectional area of the conductor which it traverses, or, in other words, upon its density.

The quantity of electricity passing through a circuit may be very great, while at the same time its potential is very small, or *vice versa.* The same phenomena may also occur in the case of heat. When the electricity is passing through a good conductor

no effect is produced by it upon the electroscope; hence, it has no perceptible tension. It is only when the wire is not capable of conveying all the electricity generated that a part of it is obstructed, exhibits the phenomena of tension, and is capable of producing an effect upon the electroscope.

If we do not connect the extremities of an induction coil, and thus leave the secondary circuit open, the positive electricity is nevertheless driven to one end of the wire, and the negative to the other by the action of the primary current. These opposite electricities, however, tend to recombine through the wire of the coil, but as this requires a certain time, the whole amount produced does not become equalized if the opening and closing of the primary circuit takes place in sufficiently rapid succession. For this reason both electricities appear in a static condition at the disconnected extremities of a very long induction coil, and present all the well known phenomena of frictional electricity. A voltaic combination, even of a thousand elements, shows in but a slight degree at its poles the phenomena of static electricity, but they are shown in the most unmistakable manner at the extremities of a powerful induction coil, which is excited by a primary current from only one or two elements. If the finger is presented to one extremity of such an induction coil, sparks may be drawn from it, and if at the same time we connect the other extremity to the earth, these become as bright and sharp as if drawn from the prime conductor of an electric machine.

Advantage has been taken of the above described properties of the induced current, in the construction of a great variety of instruments for medical purposes, as well as the extremely powerful electro-static induction apparatus of Ritchie, Ruhmkorff, and others, which will be more fully described at the end of the next chapter.

CHAPTER XIII.

MAGNETO-ELECTRIC INDUCTION.

IT has already been shown that when a primary wire traversed by a current is suddenly brought near to, or removed from the secondary wire, a momentary current is induced in the latter. Precisely the same result follows if, instead of the primary wire

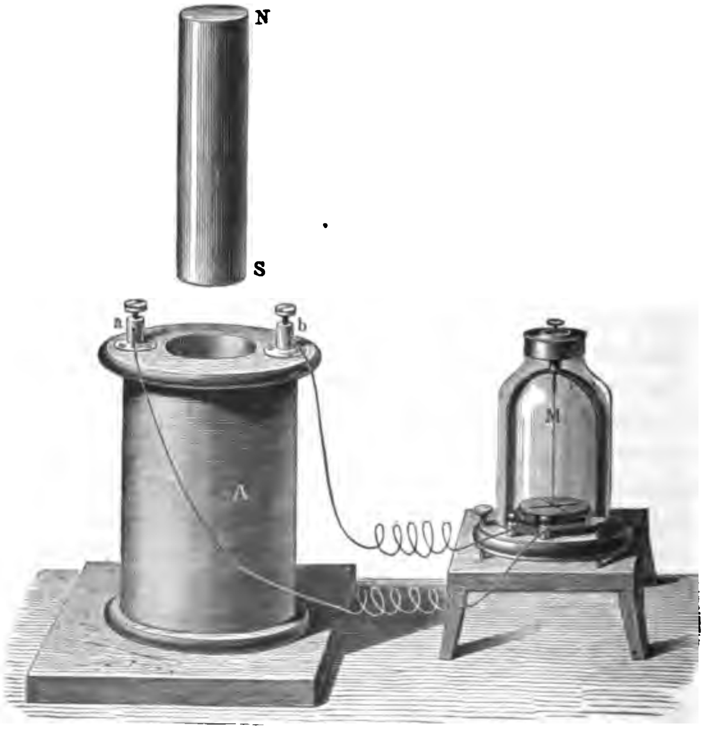


Fig. 77.

or coil traversed by a current, we employ a powerful magnet. For instance, if we suddenly place within the coil A (fig. 77,)

composed of fine and well insulated wire, a powerful magnetic bar, N S, an induced current will be set up in the wire of the coil, provided its ends are conductively connected. As long as the magnet remains at rest no induced current is manifested, but if it be suddenly removed, another induced current arises in the coil, the direction of which is opposite to that of the former one. The direction of both these currents, which are in all cases opposed to each other, depends upon the polarity of the end of the magnet which is turned towards the coil.

By causing a magnet and a coil of wire to alternately approach and withdraw from each other in rapid succession, momentary induced currents, flowing alternately in opposite directions, are produced in the wire. The importance of this phenomenon will be apparent, when we consider that it is by this means that very powerful galvanic currents may be obtained without the annoyance arising from galvanic batteries, by the mere movement of a powerful magnet in proximity to a wire coil. These galvanic currents are, it is true, only of a very short duration, and are alternately opposed to each other in direction, but in other respects possess all the qualities of ordinary battery currents, and are frequently used for medical purposes, as well as to work electric telegraphs, clocks, bells, etc.

Fig. 78.

The direction of the current induced in a closed wire coil and acted upon by a magnet, depends upon the direction of the motion (whether approaching or withdrawing); upon the direction of the turns of wire, whether the spirals are wound to the right or left; and upon the polarity of the end of the magnetic bar which is nearest when the wire coil is set in motion. In order to be able to know beforehand the direction of the induced current which will be produced by the motion of a magnet, we

may, with Ampere, look upon the magnet as a system of galvanic currents which surround the iron core perpendicularly to its length. The direction of these ideal currents is found by means of the rule previously given.

After this let us look at the south pole and imagine the magnetic bar, as in fig. 78, surrounded by currents in such a way that they pass around the south pole in the direction of the hands of a clock. If in this way we suppose the magnet to be a system of galvanic currents, the same rule applies with regard to the direction of the induced currents produced by the movements of the magnet. This rule has been previously given in reference to the movement of a wire coil traversed by a current to and from an induction coil.

The induced current which is generated in the coil A when the south pole S (fig. 77) is inserted into it, has a direction opposite to that of the hands of a clock, without reference to the direction of the turns of the coil. Therefore, upon the front side of the coil A, which is turned towards the spectator, the induced current passes from right to left. When the south pole is withdrawn from the coil the induced current is in the opposite direction, or from left to right.

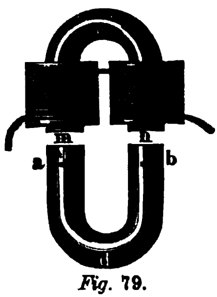


Fig. 79.

Instead of making use of a magnet and a wire coil in the manner above described, we may enclose a piece of soft iron, in the form of a horseshoe, *c*, with a helix of wire (fig. 79), and induce a magnetism in it by bringing it rapidly into proximity with a steel magnet, *a b*.

Thus, when we bring the soft iron *c* near a steel magnet, the iron itself becomes magnetic; and hence the movement of the

iron core *m* and *n* towards the poles *a* and *b* gives rise to the same action as that which occurs when a magnet moves towards a wire coil.

By the removal of the soft iron *c* from the magnet *a b*, it again loses its magnetism, and thus the withdrawal of the iron cores *m n* from the poles *a b* gives rise to precisely the same phenomena which occur when a magnet is removed from a wire coil.

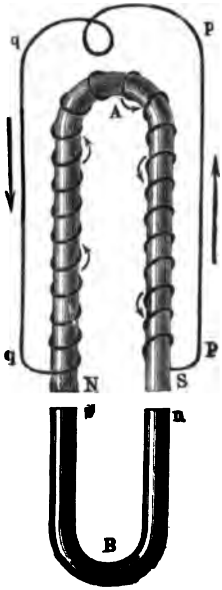


Fig. 80.

If, therefore, we give the iron core *c* with its helices a rotary motion, so as to cause the extreme ends *m* and *n* to pass close to the poles *a* and *b* of the permanent steel magnet, then, when the end *n* moves away from the pole *b*, and *m* from *a*, the removal of coil *n* from the south pole *b* causes an induced current in the same direction as the current which arises upon the removal of coil *m* from the north pole *a*.

In order to clearly understand this, it may be well to bear in mind that the direction of the turns of the wire coil, as represented in fig. 79, exactly correspond to those of the wire in the helix of an electro-magnet.

Fig. 80 represents an electro-magnet in which the turns are somewhat separated from each other. When a non-magnetic horseshoe A is brought close to a permanent steel magnet B, there arises in the former a magnetic action. A north pole N is suddenly formed opposite to the south pole *s*, and a south pole S opposite the north pole *n*. The effect of this magnetic action upon the helix is the same as if the north pole of a magnet were inserted into it at N and a south pole at S; that is, a current is induced in each leg. The directions of these currents, as indicated by the arrows, are apparently opposite to each other in the different legs, but are really in the same direction, and mutually reinforce each other in the wire *p q*.

During each half revolution of the helices *c* (fig. 79) two induced currents in the same direction are generated in the connecting wire, while the helices are approaching the poles of the permanent magnet *a b*, but during the next succeeding half revolution two other induced currents are generated, which, in consequence of the removal of the helices from the magnet poles, have an opposite direction with respect to the first pair of currents.

THE MAGNETO-INDUCTION MACHINE.

When we attach to the helices (fig. 79) suitable arrangements by which it may be put in rapid rotation, we have what is termed a magneto-electric machine, which produces a series of induced currents in quick succession, and which may be used to decompose water, produce sparks and physiological phenomena, magnetize soft iron, and even to work telegraphs and clocks.

Fig. 81 represents a machine of this kind, such as are constructed at the present time in great perfection.

R R′ are the inductor coils, enveloping the soft iron cores, which are connected by an iron yoke. They are so arranged as to be capable of rapid rotation by means of a crank, passing as close as possible to the poles of a steel magnet, and each core becomes thereby transformed alternately into a north and a south pole as it revolves.

The terminals *a b* serve to conduct the induced currents from the helices, either to the human body, or, if it is desired to produce mechanical effects, to other suitable apparatus. They are connected directly to the pole-changer, the office of which is to change the currents of opposite direction, which arise during

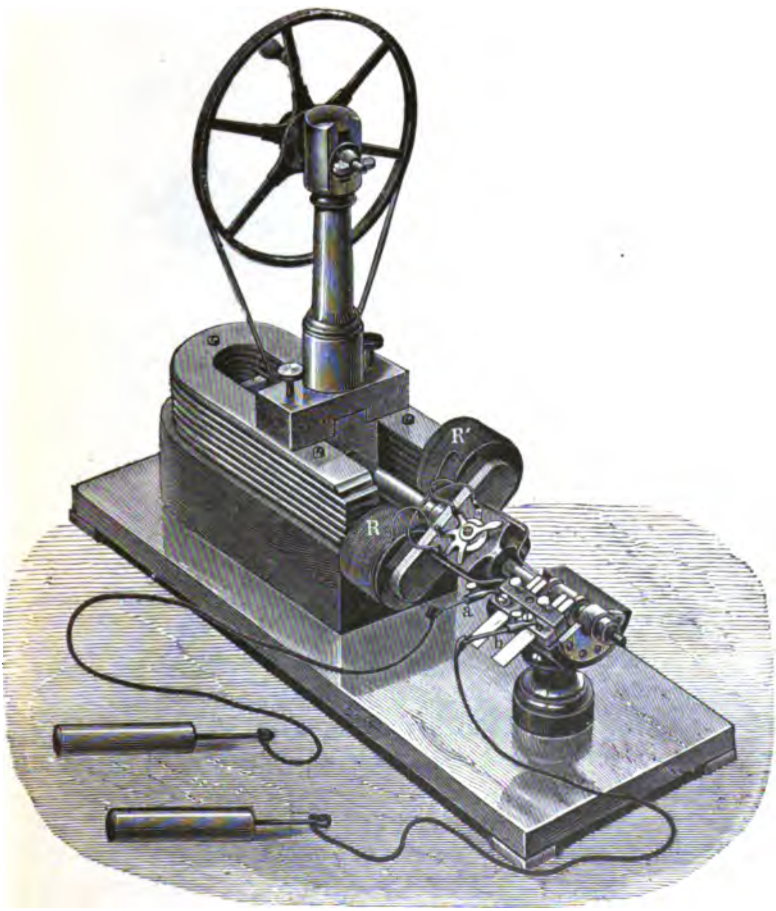


Fig. 81.

each half revolution, into currents of the same direction, and thus cause the machine to furnish only currents of one and the

same polarity. The construction of this device, which is sometimes called a *commutator*, may be easily comprehended by reference to the sectional view (fig. 82), and the perspective view (fig. 83). *m* is a brass cylinder, upon whose extreme ends two steel half-rings, 2 and 3, are soldered in such a manner that they lie exactly opposite to each other, with the ends slightly projecting. Within this cylinder *m*, but separated from it by a thin insulating bushing of boxwood (in fig. 82 the section of boxwood is represented in black),

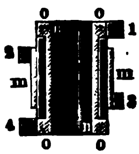


Fig. 82.

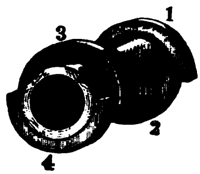


Fig. 83.

is inserted another brass cylinder *n n*, which projects beyond the tube in both directions, and carries upon its projecting portions two other steel half-rings 1 and 4, which correspond with the former pair 3 and 2, as very distinctly shown in fig. 83. Hence, while rings 2 and 3, and also rings 1 and 4 are in conducting connection with each other, the first pair of rings is insulated from the second by the boxwood.

One end of the wire of coil R (fig. 81) is in permanent connection with ring 1, and the end of coil R′ with ring 2.

The entire apparatus above described turns round with the axis. *a* and *b* are two thin steel springs, each of which is attached at one of its ends to the machine, the other end being split, so as to press with considerable elasticity against the rings 1, 2, 3 and 4 as they revolve.

The brass supports, to which the springs are attached, are provided with binding-screws for the attachment of wires, by which the current may be conducted to any required point. The device which is placed between the coils R R′ and the commutator or pole-changer, serves for purpose of combining the several convolutions of the coils in various ways. In one posi-

tion it unites the ends of both coils so that the turns form one continuous wire; in the other position it connects the front ends of both coils with each other, and the rear ends in like manner. In the former case the current passes through the entire length of the single wire, forming what is called an intensity inductor; in the other case the length of the wire in circuit is reduced to

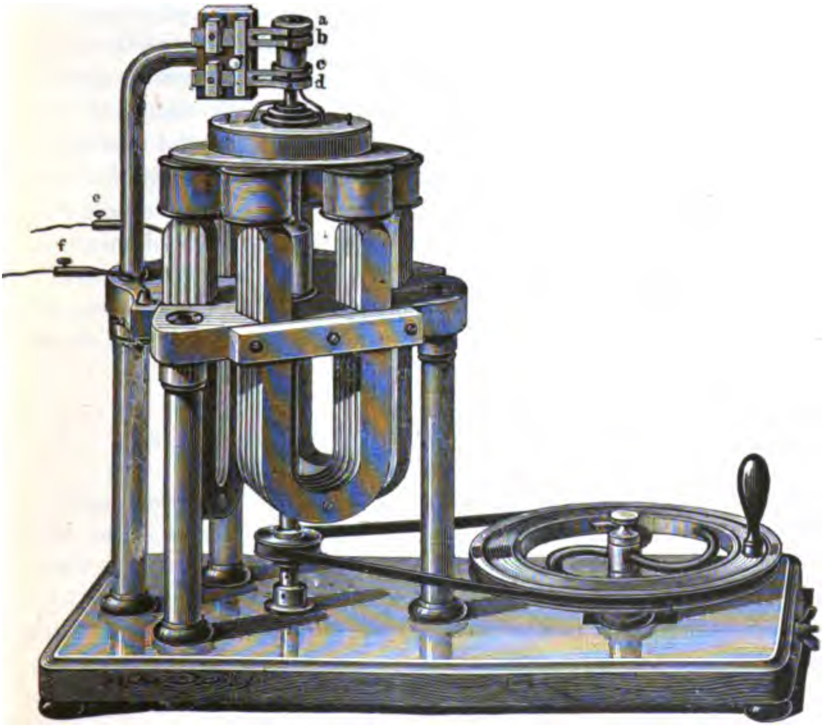


Fig. 84.

one half, and the cross-section is doubled, forming a quantity inductor. Hence, in the first case, the resistance of the coils is four times as much as in the latter case.

Another construction, likewise employed by Stöhrer in a magneto-electric machine of large size, is represented in fig. 84. This consists of three upright magnets with six induction coils.

The direction of the turns of each coil is necessarily so arranged that the induction currents which arise when the coils are approaching the several magnetic poles are of the same direction. When the coils are moving away from the magnetic poles, we again obtain currents of the same direction, which are, however, in reverse direction to the preceding one. Hence, the machine, at each complete revolution of the vertical axis which carries the coils, generates twelve currents which are alternately in one direction and the other. Each of these 12 currents consists of 6 elementary currents, which are generated simultaneously in each coil, and always unite to form a single powerful current.

The larger magneto-electric machines, as constructed for producing the electric light, are used for lighthouses, vessels, etc., and contain from 50 to 60 very powerful systems of magnets, between whose poles the same number of powerful wire coils are made to rotate. The movement of these coils, which are fixed on a common axis, is accomplished by means of a steam engine of several horse-power.

THE GRAMME MAGNETO-ELECTRIC MACHINE.

This machine differs from all other forms of electro-magnetic or magneto-electric machines by furnishing a uniform and constant current in one direction, while all others give intermittent and alternating currents, which have to be arranged by the commutator. The reason of this is that in all the other machines the wire in which the current is set up is constantly altering its position in the magnetic field, and is as a whole subjected to a growing and diminishing action in two opposite directions, hence, the electro-motive force set up is of the nature of a succession of waves alternately rising above and sinking below the zero line; and the current resembles the stream set up by strokes of a pump. In the Gramme machine, although each part of the wire is constantly changing its relation to the acting magnetic field, yet the wire, as a whole, never changes its relation to or position in the field; hence, the inductive con-

ditions set up are constant; the electro-motive force set up is of the nature of a constant fall of water, and the current is a steady stream. The characteristic feature of this important invention consists in the construction of the armature. This armature is no longer a bar, or a horse-shoe, but a complete ring of soft iron. The wire is no longer a length of wire having two ends forming a constant circuit, but it is a continuous and endless piece of wire wound over every part of the ring. The current does not flow through this circuit in its entirety, first one way and then the other, but two opposing currents flow in those parts of the wire which occupy, at each instant, a fixed relation to the inducing magnet, or rather no current flows at all in the circuit, but two equal and opposite electro-motive forces are set up, which unite in producing current if an external conductor is provided.

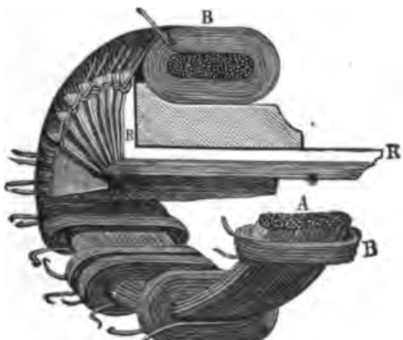


Fig. 85.

Round a ring of soft iron are wound a number of equal lengths of insulated copper wire, and a movement of rotation is imparted to the whole, when a current of corresponding strength is induced in the revolving helices. This peculiarity of construction will be understood by referring to Fig. 85, which is a section of the annular core. It shows several segments of the covered wire with the free ends projecting from the ring. These are attached to copper strips R, which, in turn, are in electrical communication with copper sectors R fixed on the spindle of the machine.

The two ends are connected with two consecutive axial conductors, while the lengths themselves are insulated from one another by layers of silk. Each coil of the wire thus appears like an element of a battery yielding its contribution to the aggregate current.

The different parts of the armature, as it revolves, are constantly changing their positions in the magnetic field, and, therefore a temporary or shifting connection to the wire has to be made as each of its turns crosses the vertical line. If the wire were a single layer this could be accomplished by exposing its exterior surface and arranging a spring to touch at each point. Practically, this same condition is attained by dividing the wire into a great number of equal sections, and attaching a conductor to each section in such way as to act as would the single turns of the wire itself. This is effected by bringing these conducting branches out to an insulated cylinder faced with as many insulated contact pieces as there are sections of wire to be connected. Brushes of thick wire are provided as springs, which press on the contact pieces and make, practically, a constant connection with the two halves of the circuit on the vertical line.

In all other forms of the electro-magnet and magneto-electric machine, the armature, as a whole, reverses its relation to the magnetic field, and assumes two distinct conditions at different times. In the Gramme, the different parts of the armature assume these conditions successively, and thus set up a rotation of the molecules of the wire, as in other machines; but, as a whole, the two distinct conditions are assumed at the same time in the two halves of the armature on each side of the vertical line.

In the revolution of an ordinary armature the electro-motive force set up in the wire, as a whole, varies with its distance from the inducing magnet, and, in consequence, the current produced is variable. In the Gramme the various sections of the wire occupy all these different positions at once; the consequent variable electro-motive forces are, therefore, generated

in them as in the ordinary armature; but these sections being connected together in series, they act exactly as do a series of cells of different electro-motive forces, and the resulting electro-motive force in each of the sides of the ring is constant, and is the sum of all those of the sections it contains. The action of the two halves of the ring corresponds, therefore, in all respects with that of the two equal batteries shown in figure 86, as coupled in multiple arc. In both there are equal opposed forces, resulting in static equilibrium, and in both there is combined action on an external circuit. The wire may be stout or fine, according to the current required, or each section may consist of a flat ribbon wound in a tight spiral. The resistance obeys the law of derived circuits, and is, therefore, one quarter that of the length of wire employed.

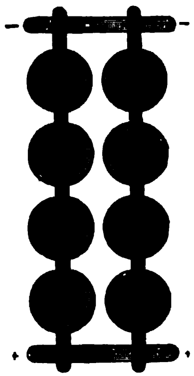


Fig. 86.

Fig. 87 represents one of Gramme's machines of the smaller type, specially constructed for the laboratory and lecture table.

These machines afford a very striking instance of the transformation of motion into electricity, and conversely of electricity into motion. This latter may easily be shown by connecting the two collecting brushes with a galvanic battery. As soon as the circuit is completed the armature begins to revolve with a speed proportional to the strength of the current. This experiment may also be repeated and with enhanced effect by means of two

machines. If they are placed so as to form one circuit, it will be seen that, by rotating one armature, the second one is set in motion and reciprocally. If the direction of rotation be suddenly reversed the second armature will suddenly stop, and almost directly recommence revolving in the opposite direction. Another very striking experiment bearing on this subject is made by introducing a length of platinum wire into the circuit. While the two machines are in motion the temperature of the platinum

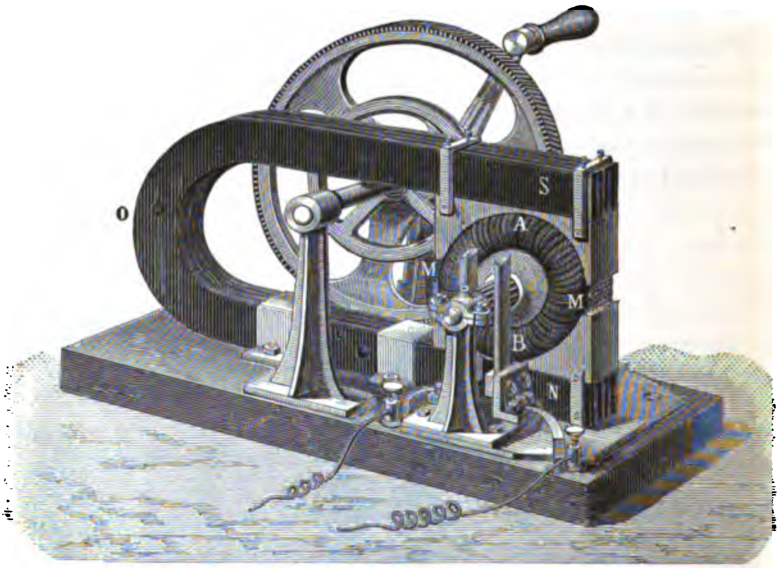


Fig. 87.

is not affected; but if one be stopped the wire is raised to a red heat, thus rendering visible the mutual convertibility of heat, motion and electricity.

PRACTICAL APPLICATIONS OF THE INDUCED CURRENT.

Induced currents, especially when generated by the action of a magnet, are for many reasons to be preferred to those pro duced by galvanic batteries. The annoyance and expense of maintenance, inseparable from the use of a battery, is sometimes an important consideration, while the magneto-induction ma

chine, although its first cost is greater, entails but a nominal expense for its operation and maintenance.

In order that the induced current may be weakened as little as may be, the resistance of the external circuit ought to be made as small as possible in proportion to the total resistance, or else the resistance within the coils of the magneto-induction apparatus ought to be proportionally great, which may be accomplished by forming the coils of many convolutions of a long and thin copper wire.

It follows from this that the magneto-electric machine is only capable of being applied advantageously upon telegraph lines of moderate length, such as private lines and municipal telegraphs, for the reason that, upon a long wire, the greatly increased resistance of the circuit renders it necessary that the resistance of the coils of the magneto-electric machine be correspondingly increased, and this, if carried too far, is unfavorable to the durability and economical maintenance of the apparatus. On the other hand, the electro-motive force or potential of the currents for working telegraph lines need not be very great, especially when the circuit consists partly or wholly of submarine cables or underground lines, as currents of too great power would have a tendency to injure the insulating coating of the conductor.

We have before seen (page 126) that the currents produced by the revolutions of the armature of a magneto-electric machine are alternately of opposite polarity or in opposite directions to each other, four separate and distinct currents being produced during each revolution. It is obvious that in this form the apparatus is not very well adapted to telegraphic purposes, but modifications of the original plan of construction have been made, in which the current increases regularly twice during each rotation and decreases in the same manner, the two impulses being in opposite directions to each other. By arranging an electro-magnet in such a manner as to be acted upon by these currents of alternate polarity, electric telegraphs may be successfully operated.

CHAPTER XIV.

THE ELECTRO-STATIC OR INDUCTION COIL.

It has been proved by experiment, that the quantity of electricity traversing the secondary wire of an induction coil is the same, whether the current is produced by the closing or by the opening of the primary circuit. The difference between the two currents in respect to their electro-motive force is, however, very marked, that of the opening current being far greater than that of the closing one, although, as above stated, the actual quantity of electricity is the same in both cases. The reason of this is that when the primary or battery circuit is closed, it is opposed by the extra or self-induced current, and hence the former requires a certain length of time to attain its full force. When, however, the primary circuit is broken, the extra current is this time in the same direction, and therefore does not delay the action to the same extent as in the first instance. The primary current disappears almost instantaneously, or at all events in much less time than is required for it to attain its full strength. The duration of the induced or secondary current corresponds with the time occupied in the charging or discharging of the primary wire by the battery current. As the same quantity of electricity is produced in the secondary wire in each case, it is obvious that it must necessarily pass through the circuit in a shorter time at the breaking than at the closing of the primary circuit, and thus its potential or electro-motive force must be correspondingly greater.

The most striking example of this action is afforded by the electro-magnetic induction coils of Ritchie, Ruhmkorff, Ladd, and others, which are now made to produce the most powerful electro-static effects, far surpassing those of the frictional electric machine.

The discovery of the electro-static properties of the induced or secondary current was made by Prof. C. G. Page, of Salem, Mass., who, in 1836, published the first account of an induction apparatus consisting of a primary coil with a secondary coil wound upon it of many times its own length. Prof. Page was also the originator of the automatic circuit-breaker, and of the devices for rendering the same adjustable. Ruhmkorff, of Paris, constructed, in 1851, the coils which bear his name. By careful insulation of the secondary wire he succeeded in producing sparks of nearly one inch in length, capable of charging a Ley-

Fig. 88.

den jar with great rapidity. Ritchie, of Boston, in 1857, vastly improved the induction coil, and in successive instruments obtained sparks of six, ten and one half and twelve and one-fourth inches. The cause of the superiority in Ritchie's coils is due chiefly to an improved method of winding the fine wire coil, by which it has been found possible to use with success a wire of several hundred thousand feet in length, while the limit in the instruments as constructed by Ruhmkorff was about ten thousand feet. Figure 88 shows the external appearance of one of

Ritchie's medium sized coils, giving a spark of nine or ten inches in length.

The chief parts of this apparatus are the primary and secondary coils, an interruptor to the primary circuit, and the condenser. In the instrument shown in Fig. 88 about 68,000 feet of silk covered wire, .012 inch in diameter, is wound upon the exterior coil. The primary or inducing coil consists of about two hundred feet of copper wire, one-seventh of an inch in diameter (No. 9), the ends of which terminate in binding screws upon the base. A heavy glass bell, seen at the top of the coil, insulates the primary from the secondary circuit, its foot being turned outwards by a flange as wide as the thickness of the coil. The induction coil, for more perfect insulation, is also encased in thick gutta percha. The ends of this coil are carried by gutta percha covered conductors to the two glass insulating stands, seen at the rear of the instrument, where they end in sliding rods, pointed with platinum at one end, and having balls of brass at the other. The interruptor devised by Mr. Ritchie consists of a toothed wheel which raises a spring hammer, the blows of which fall upon an anvil, breaking contact between two heavy pieces of platinum. The European induction coils are usually provided with an automatic circuit-breaker, but comparative trials have shown that there is an advantage in varying the rapidity of the interruptions, according to the class of effects to be produced, and that a certain time is requisite for the complete charge and discharge of the soft iron wires which form the core, longer than the automatic circuit-breaker allows.

The object of the condenser is to destroy by induction the greater part of the force of the extra current, which would otherwise materially diminish the power of the apparatus. In the instrument shown in the figures the condenser consists of 144 square feet of tin foil, divided into three sections (two of 50 and one of 40 feet), carefully insulated by triple folds of oiled silk, and placed within the base of the instrument. The battery force needed to operate this instrument consists of two or three large sized Bunsen cells.

Figure 89 shows the internal construction of one of the large horizontal coils of recent construction, arranged upon Ritchie's plan, which has been adopted, with slight modifications, by the leading instrument makers of every country. C is the core, consisting of a bundle of soft iron wires. This is separated, by a thin layer of some suitable insulating material, from the primary coil, which usually consists of two or more layers, contained in the space P P. The two coils are separated by two heavy glass tubes, B B[1], closed at the outer ends, while their open ends meet in the middle of the coil. D D is a hard rubber bobbin, the tubular portion of which is thinnest in the middle and thickest near the ends, as shown in the figure. A great number of thin insulating discs, *d d*, of

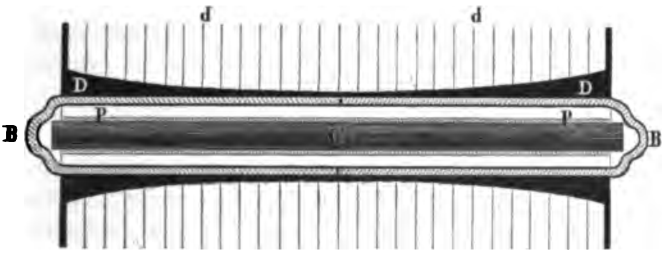


Fig. 89.

which only a few are shown in the figure, divide the bobbin into compartments, the wire being wound up in flat spirals, two or more of these occupying the space between each two adjacent discs. The various compartments communicate with each other, so that the secondary wire is continuous from end to end. The coating of silk and varnish upon the wire affords sufficient insulation between the convolutions in each compartment, and the discs prevent the spark from striking through between the compartments. The coil may thus be said, as it were, to be insulated wholesale and retail, and the separation from each other of the different parts is complete. In regard to the external insulation, less is required in the compartments in the middle of the coil, where the tension is smallest, and there is the least

danger of the electricity breaking through into the primary coil. The greatest tension is found in the compartments nearest the two ends of the coil, which is the reason why the tube is made thinnest in the middle and thickest at the ends. Another reason is that the thickness at the ends lessens the inductive Leyden jar action between the ends of the primary coil.

The largest induction coil yet made is that of the Royal Polytechnic Institute of London. The length of this coil is nine feet ten inches, diameter two feet, weight 15 cwt., including 477 lbs. of hard rubber. The core is five feet long and 4 inches diameter, of No. 16 iron wire. The primary coil consists of 145 lbs. = 3,770 yards of No. 13 wire. The secondary coil consists of 150 miles of wire, weighing 606 lbs., and having a resistance of 33,560 ohms. The condenser is in six parts, each containing 125 square feet of tin foil. With five large Bunsen cells the spark is 12 inches in length, and with 50 cells this has been increased to 29 inches.

The induction coil constructed by Ritchie for the Stevens Institute of Technology at Hoboken, N. J., has a primary coil consisting of 195 feet of No. 6 wire. The secondary coil is over fifty miles in length, of No. 36 wire. The core is composed of a bundle of No. 20 iron wires, wrapped in oil-silk and cloth. With 3 large bi-chromate cells this coil has given sparks 21 inches in length, capable of piercing through solid glass three inches in thickness.

CHAPTER XV.

APPARATUS FOR ELECTRICAL MEASUREMENT.

It has already been stated, that the deflections of the needle of a galvanometer are not in direct proportion to the strength of the galvanic current by which they are produced. If, for example, a given current deflects the needle through an angle of 10°, it by no means follows that a current is twice as powerful which gives a deflection of 20° upon the same instrument.

The reason of this is, that the separate convolutions of the multiplier or conducting wire cannot all be placed at the same distance from or in the same relation to the needle, and thus the deflecting power of the coil does not increase strictly in proportion to the number of convolutions. The ordinary multiplier, therefore, although well enough adapted to the mere purpose of detecting the presence or direction of a galvanic current, is by no means suitable for the measurement or quantitative comparison of currents of different degrees of strength. The reason of this is, that the action of the current upon the needle has a tendency to deflect the latter so as to bring it into a position at right angles to its own course, and, therefore, the farther the needle moves from a position parallel to the plane of the coil, the more nearly does it approach a right angle, where the effect is of course null; so that the influence of the current becomes gradually less and less powerful, in proportion as the deflection becomes greater. In order to overcome this difficulty, several different kinds of galvanometers have been invented, in which a trigonometrical function of the angle of deflection produced by different currents, such for example as the tangent or sine, is strictly proportional to the strengths of these currents.

THE TANGENT GALVANOMETER.

This valuable instrument was invented by M. Pouillet, who was also the first to employ it for the measurement and comparison of electric currents. Figure 90 shows the form in which it was first constructed.

Upon the wooden table K K a circular ribbon of copper L L is placed parallel to the plane of the magnetic meridian. This ribbon is from 15 to 20 inches in diameter, 1 inch wide, and $\frac{1}{12}$ inch thick, and its two extremities are bent vertically so as to dip into two glass vessels V V′, filled with mercury and connected with the poles of the battery by means of the wires *l l′*.

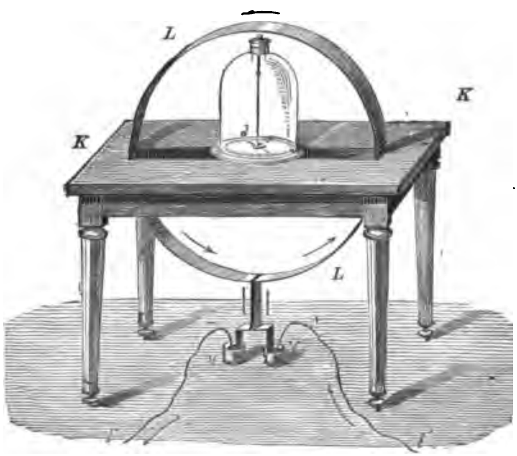


Fig 90.

In the centre of the ring L L a short and thick needle is suspended, by means of a silk thread without torsion. A very light copper or wooden index, *d*, fixed at right angles to the axis of the needle, indicates upon a graduated horizontal scale the angular movements of the magnet.

When the current traverses the ring L L the needle is deflected, but in consequence of the breadth of the copper ribbon and the shortness of the needle, the resultant of the actions ex-

ercised by the circular current upon the needle is always nearly at right angles to the magnetic meridian.

If, therefore, we call i the force of the current, or its action on the needle placed in the plane of the magnetic meridian, this action will become i cos. d when the needle has reached an angular deviation d. But in this position the directive power of the needle (which is, of course, equal and opposite to the action of the current) is f sin. d. Thus we have:

$$i \cos. d = f \sin. d;$$

Therefore,

$$i = f \frac{\sin. d}{\cos. d},$$

And

$$i = f \operatorname{tang.} d.$$

With a galvanometer of this form, therefore, the strengths of the current successively transmitted through the ring L L bear the same relations to each other as the tangents of the angles of deviation of the magnetic needle.

More recently M. Gaugain has modified in a very successful manner the construction of the tangent galvanometer. His arrangement is based upon the following theorem, which was deduced by M. Bravais from the formula of Ampère:

"If a magnetic needle is submitted to the action of a circular current set up in the plane of a magnetic meridian, and the centre of the needle occupies the apex of a right cone, having for its base the circular current, the tangent of the deflections of the needle are almost absolutely proportioned to the strength of the current, if the height of the cone is equal to a fourth part of the diameter of the base."

Experiments show that with needles of $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in length, and circular currents, of which the radius is at least three times the length of the needle, if the conditions which are enumerated in this theorem are fulfilled, the limit of error does not exceed $\frac{1}{1800}$; an amount so insignificant that it may be altogether disregarded in practice.

Tangent galvanometers are constructed upon the above principle, which are at the same time very accurate and very sensitive, and the diameters of which are sometimes not more than 7 or 8 inches.

In Gaugain's tangent galvanometer (fig. 91) the magnetic needle, its index, and its horizontally divided circle are carried by a support P, which may be removed from or drawn nearer to the circular frame A, around which is coiled the insulated copper wire *t t'*. The point of suspension of the needle is upon a

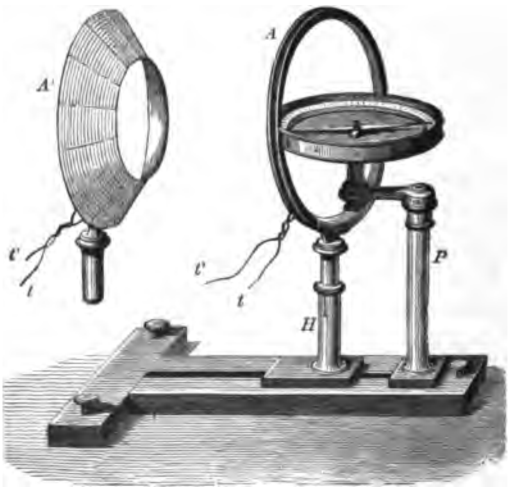


Fig. 91.

horizontal disc or circle placed in the centre of the ring A, at right angles with its median section, and at a distance from this plane equal to a fourth part of the diameter of the circular current.

M. Gaugain, starting from the same principles, has constructed tangent multipliers, by means of which the strength of the feeblest currents can be measured with great accuracy.

For any given position of the magnetic needle, the geometrical place of all the convolutions which is most suitable for the construction of a galvanometer is a cone, whose apex is in the

centre of the needle, and whose angle is determined, the relation of its height to its base being known. If, upon the surface of this cone, an insulated copper wire is coiled, and the current is transmitted through it, each convolution of the wire tends to produce a deflection of the needle, whose tangent will be proportional to the strength of the current. It is evident that the conical multiplier, formed by the aggregate of these convolutions, will possess the same properties.

In order to transform the tangent galvanometer into a tangent multiplier, it is only necessary to detach the circle A from its stand H, and to substitute for it the frustrum of a cone A′, upon the outer surface of which an insulated wire *t t′* is coiled. The conical multiplier is very sensitive, and very convenient for practical work. The centre of suspension of the needle must always occupy the apex of the cone, of which A′ is the frustrum.

The modifications introduced by M. Gaugain in the construction of the tangent galvanometer render his apparatus superior to all others for exact measurements.

The cone A′ may be wound with two wires of equal size and length, so that the instrument may be used as a differential galvanometer if desired.

Several of these instruments are employed in the service of the Western Union Company, and are found very useful and convenient, especially for measuring the internal resistance of batteries, for which they are not excelled by any other apparatus in use.

THE SINE GALVANOMETER.

The principle upon which the sine galvanometer is constructed is illustrated in the diagram fig. 92. The line *s n* represents a magnetic needle at rest in the meridian. If the needle is deflected through the angle α, by the influence of a galvanic current *a b* flowing in the same plane, then the line *n′* M, drawn parallel to *s n*, will represent the direction of the earth's magnetic force, which constantly tends to bring the needle back to

its position in the meridian. The intensity of this force is represented by the length of the line n' M, and is denoted by M.

In order to ascertain what portion of this force acts upon the needle, we may resolve n' M into two forces, viz., $n' f$ acting in a direction at right angles to the needle, and $n' g$ in a direction parallel to it. The latter, however, is entirely exerted upon the fixed turning point. Therefore, $n' f$ represents the actual force of that portion of the earth's magnetism which tends to bring the needle back to the meridian $s\ n$. Thus we have

$$n' f = n' \text{ M. sin. } \alpha = \text{M. sin. } \alpha.$$

Thus the force of the earth's magnetism, which tends to bring a deflected needle back to its state of rest in the meridian, is

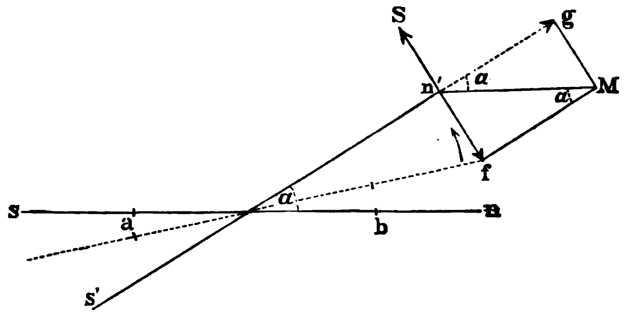


Fig. 92.

always equal to M. sin. α, in which M remains constant, so long as the needle remains at the same point on the earth's surface, and retains its original magnetism.

The coil of the sine galvanometer must first be placed parallel with the magnetic meridian. When the needle is deflected by the passage of the current through the coil, the latter is turned after the needle until it coincides with its new direction. To illustrate this, let $s\ n$, fig. 92, represent the needle at rest in the meridian, and $a\ b$ the galvanometer coil parallel thereto. Now, suppose that the passage of the current deflects the needle and causes it to assume the position indicated by the dotted line, and that the coil $a\ b$ is then turned in the same direction, until

it also coincides in direction with the dotted line; the needle will be deflected still further in the direction of the arrow, because the tendency of the current is always to bring the needle into a position at right angles to its own course; but this is constantly opposed by the directive force of the earth's magnetism, tending to carry it back to the meridian. By continuing the movement of the coil in this direction, a point is at length reached at which the coil and the needle are again parallel, which is represented by the line $s'\,n'$. The influence of the galvanic current upon the needle is still exerted, as before, in a direction at right angles to the conducting wire, denoted by the line n' S, while that portion of the earth's directive force which acts upon the needle is represented by $n'f$. The needle being at rest under the combined influence of these two forces, it follows that the forces must be equal to each other. The force n' S is, therefore, exactly equal to $n'f$. But $n'f = $ M. sin. α; consequently

$$n'\,\mathrm{S} \text{ or } \mathrm{S} = \mathrm{M} \sin.\ \alpha.$$

If we allow another current to pass through the same coil, and again turn the coil towards the deflected needle until the two again coincide in direction, and denote this current by S′, the angle of deflection by α'

$$\mathrm{S}' = \mathrm{M}.\ \sin.\alpha';$$

and for both currents,

$$\mathrm{S} : \mathrm{S}' = \sin.\ \alpha : \sin.\ \alpha'.$$

That is to say, the magnetic forces of two galvanic currents are to each other as the sines of the angles of deflection of the needle, in cases when the galvanometer coil has been turned after the needle, until the direction of the two is coincident.

The sine galvanometer is founded upon these laws. Its essential parts will be easily understood by reference to fig. 93. In the centre of the divided horizontal ring is placed the magnetic needle, while the vertical ring contains the conducting wire. The whole is so arranged as to be capable of being turned around its vertical axis, and the angle through which it is turned may be read off from the graduated horizontal circle below.

When using the instrument, the index on the lower graduated circle is placed at zero, and then the coil is turned until it stands in the magnetic meridian, so that the needle points to zero of the upper graduated circle. If we now allow the current which is to be tested to pass through the coil, the needle is deflected. The vertical ring, which contains the conducting wire, is turned in the direction of the deviation of the needle, until the two are brought into the same vertical plane, and the needle again points to zero, the upper divided circle having kept com-

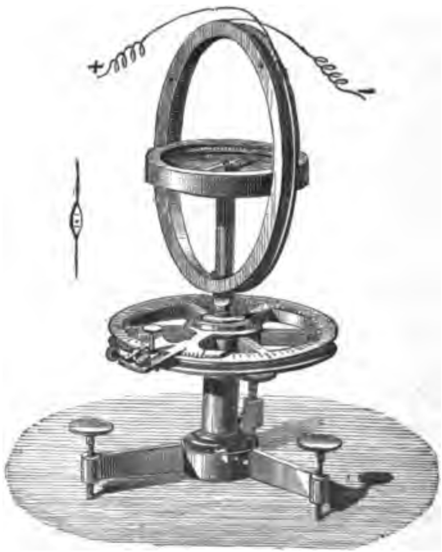


Fig. 93.

pany with the coil in turning. The deflection of the needle is then read off from the lower circle, and the sine of the angle of deflection is the measure of the strength of the current.

When the sine galvanometer is used for measuring weak currents, the convolutions of the conducting wire should be as numerous and as close as possible to the needle.

As the sine galvanometer, when properly arranged, is more expensive and not so convenient for general use as the more sim-

ple tangent galvanometer, it is but little used except for scientific experiments, especially in cases where the currents which are to be measured are not strong enough to act upon the needle of the tangent galvanometer with sufficient power.

THE ORDINARY MULTIPLIER ARRANGED AS A SINE GALVANOMETER.

It is obvious that the ordinary multiplier may easily be transformed into a sine galvanometer, when it is so arranged that the coils may be turned horizontally, independently of the needle, and a graduated horizontal circle so arranged as to indicate the number of degrees traversed upon a fixed index. But we can, with equal convenience, when there is no fixed index or graduated circle, indicate the angle through which the coil is turned by means of the multiplier, if, after the current has been made to pass through the coil, we turn the latter after the deflected needle, until they coincide and the multiplier wire becomes parallel to the needle. If we now interrupt the current the needle returns to its state of rest, and describes exactly the angle which the coil has traversed in its removal from its original position in the magnetic meridian.

If it is not practicable to turn the coil itself, we may still use the multiplier as a sine galvanometer, by placing it upon a horizontal disc, capable of being turned around a vertical axis, and provided with a graduated scale. This, of course, is managed in the same way as a sine galvanometer.

In using this instrument care should be taken to ascertain that, after a current has been measured, that the needle still retains its original magnetism. This may be very easily done by observing whether the needle, after the current has been broken, returns completely to its former position of rest, the zero point of the scale.

SIEMENS & HALSKE'S SINE-TANGENT GALVANOMETER.

This instrument may be used both as a sine and a tangent galvanometer. Its construction and arrangement is shown in fig. 94. The annular horizontal plate P, upon which the wire

ring R, and the needle-box M are fixed, may be turned by two insulated handles *u* in the plate P, of which only one is visible in the drawing.

Upon the circle Q is a graduated scale T, and upon the moveable ring P is an index mark *i*. By means of this graduated scale T the angles are read off in the manner heretofore described

Fig. 94.

when the galvanometer is to be used by the sine method. Within the needle-box is also another graduated scale T, by means of which the angles are read off, when the current is to be measured by the tangent of the angle of deflection.

The coil R consists of 16 convolutions of wire $\frac{1}{16}$th inch thick,

which proceed from screw k to screw k^{II}, and of 1050 convolutions of thin wire ($\frac{1}{100}$th of an inch), which pass from screw k^{III} to k^{IV}. The thicker coil has a resistance of less than 0.1 Siemens unit (which will be hereafter explained), while the resistance of the thinner coil is about 150 Siemens units.

When the screws k^{I} and k^{II} are connected with the poles of a battery, then the thick wire coil alone is connected; but when k^{III}

Fig. 95.

(not visible in the drawing) and k^{IV} are connected with the poles of a battery, the thin wire coil only is in circuit. By pulling out the knob u two stops are caused to project in the needle-box M, so that the swing of the needle is limited.

Fig. 95 represents the sine needle, and fig. 96 the tangent needle, both of full size. The pointers i i are of aluminium.

When the currents are of such force that it is impossible to read off the angles with accuracy, a portion only of the current is allowed to pass through the instrument. This is accomplished by inserting an additional wire between the corresponding screws of the instrument, the resistance of the wire being in a known proportion to that of the coil of the instrument. The theory of

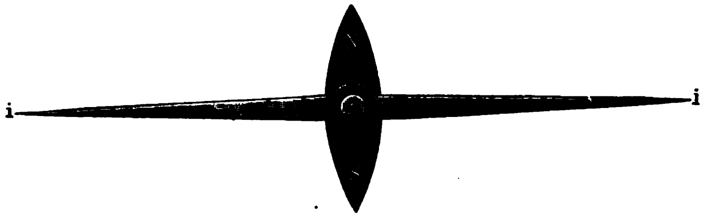


Fig. 96.

resistance and branch currents will be considered hereafter, but for the sake of completeness we will refer also to its use with the sine-tangent galvanometer, for the benefit of such persons as are already familiar with the principle.

Referring to fig. 97, suppose w to be this branch wire, while W represents the resistance of the instrument, E the battery, and S′ the current passing through the galvanometer with the

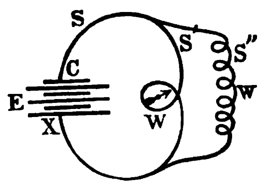


Fig. 97.

branch circuit open, S″ the current through the branch circuit only; then, if S represents the entire strength of the current of the battery in the portions of the circuit outside the galvanometer, we have:

$$S = S' + S''$$

$$S' : S'' = w : W$$

Hence,
$$S = \frac{W + w}{w} S'.$$

If we substitute in succession for w the values $\frac{1}{9}$ W, $\frac{1}{4}$ W and W, we obtain:

$$S = 10\ S'$$
$$S = 5\ S'$$
$$S = 2\ S'$$

A branch wire, thus arranged to convey a portion of the current around the instrument, is termed a *shunt*. Fig. 98 represents a box or case containing three such shunts or branch wires, the respective resistances of these wires being in the proportion above stated. The binding screw marked 0 forms the common terminal of the three shunts, while the resistances of $\frac{1}{9}$ W, $\frac{1}{4}$ W and W, proceeding therefrom, terminate respectively in the screws marked 10 5 and 2, as illustrated in fig. 99. If, therefore, we connect 0 with one of the binding screws of the sine-tangent galvanometer (fig. 94), and either 10 5 or 2 with the other binding screw, the branch circuit or shunt thus connected will divert a portion of the current, and the remainder, which

Fig. 98.

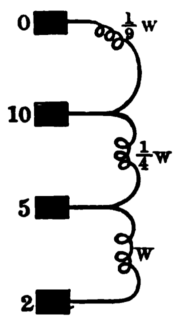


Fig. 99.

still passes through the instrument, will be only $\frac{1}{10}$, $\frac{1}{5}$ or $\frac{1}{2}$ the original amount, as the case may be; therefore, in order to obtain the true value of the strength of the current, we should multiply the sine or tangent of the observed angle respectively by 10, 5, or 2. In this manner, by the aid of shunts, it is quite possible to make use of very sensitive instruments to measure powerful currents. The combined sine-tangent galvanometer is

very well adapted for telegraphic purposes, all the measurements which were required in laying the Red Sea cable having been made with one of these instruments.

THE REFLECTING OR MIRROR GALVANOMETER.

The accuracy with which measurements can be made depends chiefly upon the sensitiveness of the galvanometer employed in making these measurements. The Thomson reflecting galvanometer supplies this requisite sensitiveness, and is the instrument which is almost invariably employed when great accuracy is required, and also when very high resistances have to be measured.

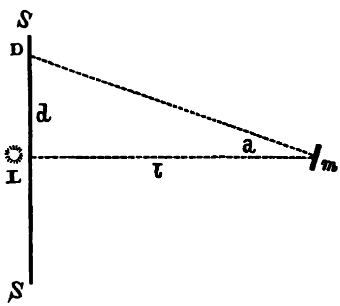


Fig. 100.

Its principle is that of employing a very light and small magnetic needle, delicately suspended within a large coil of wire, and of magnifying its movements by means of a long index hand of light. This index hand is obtained by throwing a beam of light on a small mirror fixed to the suspended magnetic needle, the ray being reflected back on to a graduated scale. The scale being placed about 3 feet distant from the mirror, it is obvious that a very small angular movement of the mirror will cause the spot of light reflected on the scale to move a considerable distance across it. The needle of the instrument being very small, and being placed in the centre of a large coil, the tangents of its deflections are directly proportional to the strength of the currents producing them.

In fig. 100 let L be a lamp which throws a beam upon the mirror m, which has turned through a small angle, and reflected the beam on the scale at D. Let d be the distance through which the beam has moved on the scale from the zero point at L, and let l be the distance between the scale and the mirror. Now the angle through which the beam of light turns will be twice the angle through which the mirror turns. This is clear if we suppose the mirror to have turned through 45°, when the reflected beam will be at 90°, or at right angles to the incident beam. If, then, we call a the angle through which the beam of light turns, $\frac{a}{2}$ will be the angle through which the mirror will have turned. Let $\frac{a_1}{2}$ and $\frac{a_2}{2}$ be the two angles through which the mirror has been turned by two currents, of strengths s_1 s_2 respectively, then—

$$s^1 : s^2 : : \tan\frac{a_1}{2} : \tan\frac{a_2}{2},$$

therefore—

$$s_1 : s_2 : : \frac{\sqrt{1+\tan^2 a_1}-1}{\tan a_1} : \frac{\sqrt{1+\tan^2 a_2}-1}{\tan a_2}$$

$\sqrt{1+\tan^2}$ being positive, as the angles are less than 90°.

z being the distance of the scale from the mirror, let d_1 and d_2 be the distances traversed on the scale by the beam of light, then—

$$\tan a_1 = \frac{d_1}{z},\ \tan a_2 = \frac{d_2}{z},$$

therefore—

$$s_1 : s_2 : : \frac{\sqrt{1+\frac{d_1^2}{z^2}}-1}{\frac{d_1}{z}} : \frac{\sqrt{1+\frac{d_2^2}{z^2}}-1}{\frac{d_2}{z}}$$

therefore—

$$s_1 : s_2 : : d_2\left(\sqrt{z^2+d_1^2}-z\right) : d_1\left(\sqrt{z^2+d_2^2}-z\right);$$

when d_1 and d_2 do not differ largely, then we may take—

$$s_1 : s_2 : : d_1 : d_2.$$

but when this is not so the error may be considerable. For instance, suppose $z = 400$, $d_1 = 150$, and $d^2 = 300$. According to the above formula this would show that one current is just twice as strong as the other, but according to the correct formula we find—

$$s_1 : s_2 :: 300\,(\sqrt{400^2+150^2}-400) : 150\,(\sqrt{400^2+300^2}-400),$$

that is—

$$s_1 : s_2 :: 8100 : 15000,$$

or—

$$s_1 : s_2 :: 150 : 278,$$

so that when extreme accuracy is required, we cannot take the strengths of currents as being proportional to the number of divisions of deflection on the scale.

The galvanometer, as usually constructed, consists essentially of a very small magnetic needle, about three-eighths of an inch long, fixed to the back of a small circular mirror whose diameter is about equal to the length of the magnet. This mirror, which is sometimes a plano-convex lens of about 6 feet focus, is suspended from its circumference by a single cocoon fibre devoid of torsion, the magnetic needle being at right angles to the fibre. The mirror is placed in the axis of a large coil of wire, which completely surrounds it, so that the needle is always under the influence of the coil at whatever angle it is deflected to. A beam of light from a lamp placed behind a screen, about 3 feet distant from the coil, falls on the mirror, the bottom of which is slightly in advance of the top, and is reflected back on to a graduated scale placed just above the point where the beam emerges from the lamp. The screen is, as we have before said, straight, and is graduated usually to 360 divisions on either side of the zero point.

The Thomson galvanometer is made in such a variety of forms that it is unnecessary to describe them all; we purpose, therefore, only to describe the most common forms in use.

Fig. 101 is a front view, and fig. 102 a side view (with glass shade, etc., removed) of one form, one third full size. It consists of a base formed of a round plate of ebonite, provided

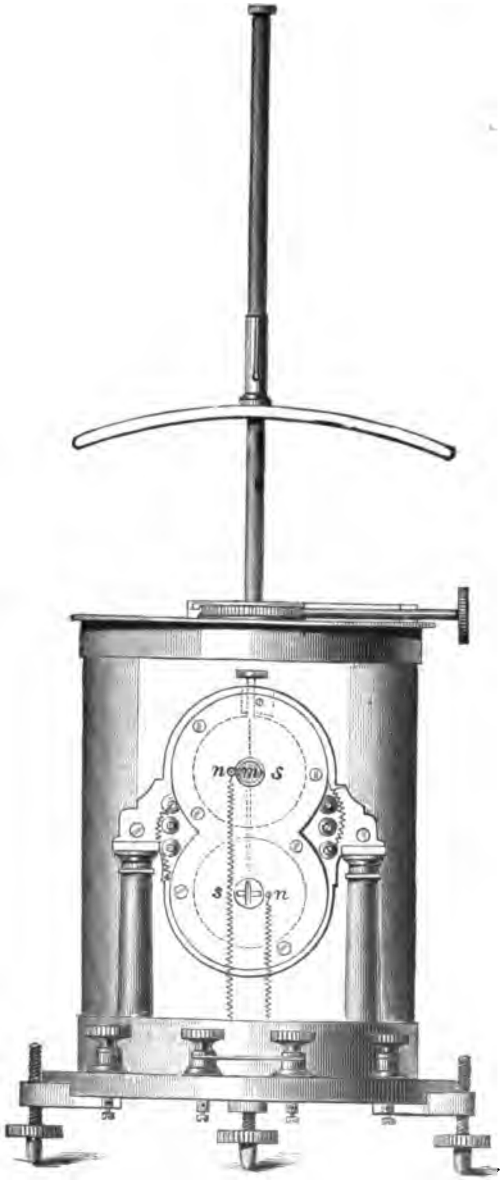


Fig. 101

with three levelling screws; two spirit levels, at right angles to one another, are fixed on the top of this plate, so that the whole instrument can be accurately levelled. Sometimes one circular level only is provided, but the double level is much the best arrangement. From the base rise two brass columns, and between them a brass plate is fixed, rounded off at the top and bottom. Against the faces of this plate are fixed the coils (c, c_1, c_2, c_3) of the instrument. The brass plate has shallow counter-sinks in its surface for the faces of the coils to fit into, so that

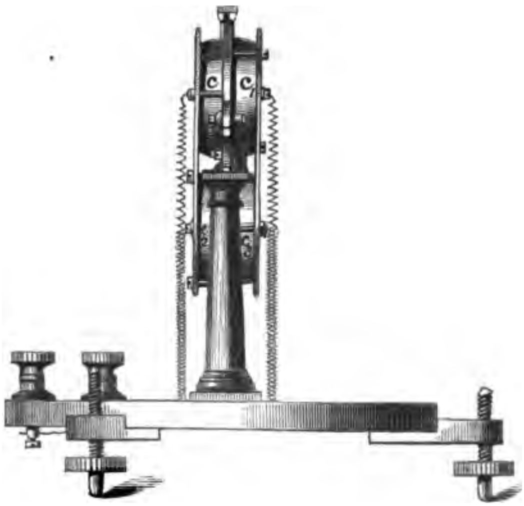


Fig. 102.

they can be put in their correct places without trouble or danger of shifting. Round brass plates press against the outer surfaces of the coils by means of screws, and keep them firmly in their places. There are two round holes in the brass plate coinciding with the centre holes in the coils. The coils themselves, which are four in number, as will be seen in the figure, are wound on bobbins of thin material, the wire being heaped up towards the cheek of the bobbin which bears against the brass plate. This heaping up is done in accordance with the law of Sir William Thomson, so as to obtain, as far as possible, a max-

imum effect from a minimum quantity of wire. The edges of the coils are covered with shellac, so as to protect the wire from mechanical injury. Within the holes in the brass plate are placed two little magnets, *n s* and *s n*, formed of watch-spring highly magnetized. They are connected together by a piece of aluminium wire, so as to form an astatic pair of needles. A small groove is cut in the brass plate, between the upper and lower hole, for the connecting aluminium wire to hang freely in. In front of the top needle is fixed the mirror. The suspension fibre is attached, at its upper end, to a small stud, which can be raised or lowered as required. When pressed down as far as it will go, the needles rest on the coils, and the tension is taken off the fibre, so that the instrument can then be moved about without danger of breaking the fibre. One end of each coil is connected to one of the four binding screws in front of the base of the instrument, the other ends being connected to one another through the medium of the little binding screws placed midway on either side of the coils. The connections are so made that when the two middle binding screws on the base of the instrument are joined together, the whole four coils are in the circuit of the two outer binding screws, so that they all act upon the magnetic needles. Some better arrangement for connecting the four coils together than that at present adopted is highly desirable, so that they could be coupled up in series, by which means the resistance of the galvanometer could be reduced to one fourth the resistance of one of the coils, that is, one sixteenth of that of all the coils together. By connecting the first binding screw on the base with the third, and the second with the fourth, the coils will be coupled up so as to reduce the resistance of the coils to one fourth of the total resistance of all the coils together. Over the coils a glass shade is placed, from the middle of the top of which a brass rod rises. A short piece of brass tube slides over this rod with a weak steel magnet slightly curved fixed at right angles to it. This magnet can be thus slid up or down the rod, or twisted round, as occasion may require. For fine adjustments a tangent screw is provided, which turns the brass rod round and with it the magnet.

We have said that the mirror is sometimes made of a plano-convex lens. This is done so as to obtain a sharp image of the spot of light on the scale. The width of this spot of light can be regulated by means of a little brass slider fixed over the hole in the screen through which the beam emerges from the lamp. A much better arrangement than the spot of light is made with some instruments. The hole through which the light emerges is made round, about the size of a sixpence, with a piece of fine platinum wire stretched vertically across its diameter. A lens is placed a little distance in front of this hole, between the scale and the galvanometer, so that a round spot of light with a thin black line across it is reflected on the scale. This enables readings to be made with great ease, as the figures

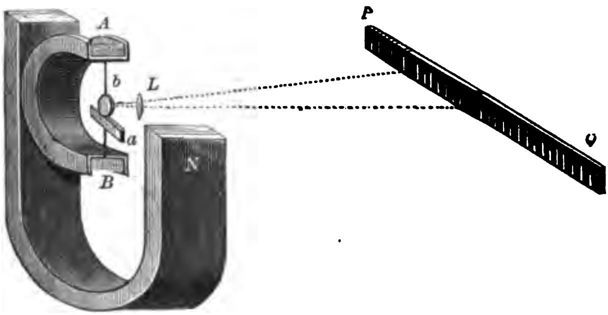


Fig. 103.

on the scale can be very distinctly seen. The mirror in this arrangement may be a plane one. When the spot of light only is used, it is necessary to partially illuminate the scale with a second lamp.

THOMSON'S MARINE GALVANOMETER.

This is a reflecting galvanometer, constructed in such a manner that the oscillations of a vessel cannot change the relative position of the small mirror and the scale when used on board cable ships, and for other similar purposes. The magnet *a* (fig. 103) is attached by means of cocoon fibres, at the top as well as at the bottom, to the little wooden frames A B, which support

the convolutions of wire. The cocoon fibres pass accurately through the joint centre of gravity both of the magnetic bar and the mirror, so that when the wire of the coil is turned the latter remains unaltered in its relative position to the convolutions. The magnet thus retains, in any position of the instrument, the same position in relation to the scale which is attached to it on the same table.

It is no less important for this purpose to have the influence of terrestrial magnetism upon the magnet destroyed. This is attained by enclosing the multiplicator wire, with magnet *a*, mirror *b* and lens L, in a case made of soft iron, and at the same time putting up in the inside of the box a moderately strong horse-shoe-shaped steel magnet N S in such a manner that its poles are nearly in contact with the coil. The magnetic action of these poles upon the magnetic needle being stronger than the attractive power of the earth, the latter is neutralized by it, and the suspended needle is maintained in a position of rest under all changes in the situation of the instrument.

The small mirror may be replaced by a plano-convex lens of 2½ feet focal length, the back of it being silver plated, and forming at the same time a small concave mirror, which reflects the falling rays in converging directions, and concentrates them upon the scale. The curvatures of the lentiform mirror are so calculated that the source of light is placed at a distance of about 1½ feet from the centre of the mirror, while the scale or the screen designed to receive the reflecting light is placed at a distance of eight feet from the focus. The screen is a flat piece of wood, covered by white paper, which is fixed on a black painted wall, as shown in figure 104 on the next page.

To avoid the disturbing movements of the spot of light upon the screen, which are caused by the shaking and flickering of the flame, the lamp is enclosed in a cylindrical case, in which, on the side turned towards the mirror, is to be found a small slit, where the flame burns gently. When the galvanometer needle is at rest, the spot of light appears exactly upon the middle of the

screen in the form of a small quadrangle of $\frac{3}{4}$ of an inch in length and $\frac{1}{4}$ of an inch in breadth. This image moves, according to the deviation of the needle, to the right or the left, and produces in this way, as in the needle telegraph, two primitive signs, by the repeating and combining of which in groups an alphabet may be constructed.

With a ship or marine galvanometer, arranged in this manner, all kinds of galvanometrical measurements can be made at sea, even in very stormy weather, as readily and surely as on land. Neither the changing course of the vessel nor the oscillations caused by the waves of the sea have any influence whatever on the movements of the galvanometer index.

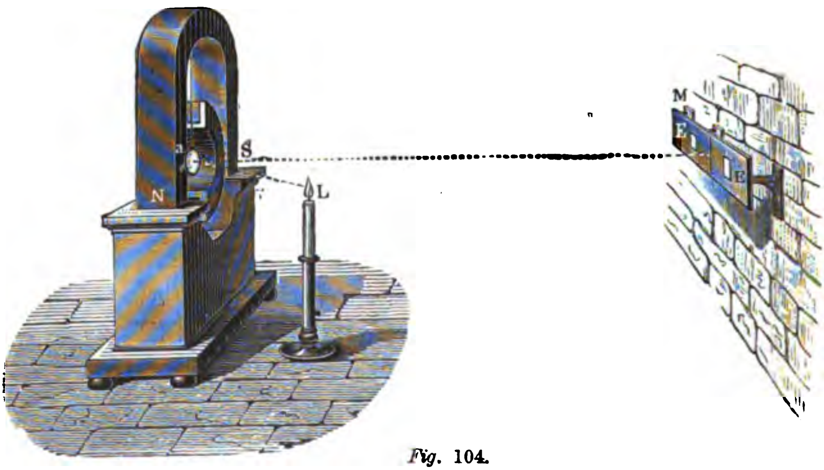


Fig. 104.

It is easy to understand that the horse-shoe magnet diminishes in some degree the sensitiveness of the instrument; on that account, when use is made of instruments of this kind as cable-speaking instruments, a somewhat stronger current must be used than would be required by the single reflecting galvanometer.

PRECAUTIONS NECESSARY IN USING GALVANOMETERS.

Great care should be taken, when using any galvanometer, not to allow too powerful currents to pass around the needle, as such currents are liable either to change the magnetic intensity

of the needle or to reverse its polarity altogether. Hence, in order to avoid the injurious influences upon the magnetism of the needle, even of feeble currents, the currents should not be allowed to act upon a galvanometer for a longer time than is necessary.

When using the tangent galvanometer, it must be remembered that the trigonometrical tangents of the angles 0° to 45° of a circle whose radius is 1, increase from 0 to 1, but that, on the contrary, for angles of 45° to 90° the tangents increase from 1 to ∞ (infinity). It follows, therefore, that at large angles, a very considerable change in the strength of the currents will produce but a slight change in the angle of deflection, and that, even in a very accurately constructed instrument, an increase in the angle of deflection is hardly perceptible; or rather is quite imperceptible, although the current-strength may have been considerably increased.

The case is similar with the sine galvanometer. The difference in the sines between 1° and 10° is very much larger than the difference in the sines between 81° and 90°. For this reason the sine galvanometer is much more accurate in the measurement of large angles than smaller ones; the reverse being the case, as we have seen, with the tangent galvanometer.

THE VOLTAMETER.

Faraday has shown that the chemical action of a galvanic circuit is equivalent to its magnetic action, and that the quantity of water decomposed in a certain time by a current; or, what is the same thing, the volume of inflammable gas evolved during that time, is in proportion to the strength of the current.

If, therefore, we take an apparatus for decomposing water, which is provided with a graduated glass tube for the purpose of retaining and measuring the inflammable gas formed by the decomposition of the water, we have an instrument termed the Voltameter, which may be employed for the purpose of comparing the strengths of different currents with each other.

Figs. 105 and 106 show the construction of the Voltameter.

The glass vessel is filled with dilute sulphuric acid, or preferably with pure sulphuric acid of 1.3 specific gravity. Through glass tubes, inserted in the leaden plug which closes the vessel at the top, pass two insulated copper wires, hermetically sealed, into the vessel, where they are soldered to two thin platinum plates, which stand opposite to each other and as near together as possible. The copper wires in the inside of the vessel are protected from the action of the acid by a coating of varnish. If we connect the ends of the copper wires protruding from the leaden plug with the poles of a battery, then the current passes from one platinum plate to the

Fig. 105.

other, through the acidulated water, which is thereby decomposed, forming inflammable gas. The latter ascends and escapes through the bent tube. In order to measure it we confine it in a glass tube, divided in cubic centimetres, as represented in fig. 107. If we wish to measure this with accuracy, and have the inflammable gas perfectly pure, the compound gas that is separated from the water should be made to pass through sulphuric acid, in order to remove any water which it might contain.

Nevertheless, it must not be forgotten that the insertion of a voltameter into the circuit of a battery, on account of the great resistance which it opposes to the passing of the electricity, materially reduces the strength of the galvanic current.

REDUCTION OF THE VOLUME OF GAS.

The use of the voltameter requires an exact measurement of the volume of inflammable gas formed by the current in a given time. The volume of a confined gas, however, according to Mariotte's laws, depends upon the pressure brought to bear on it, the volume decreasing in the same proportion that the outside pressure increases. Besides this, temperature has an important influence upon the volume of a confined gas. With respect to the latter circumstance, the careful investigations of physicists

Fig. 106.

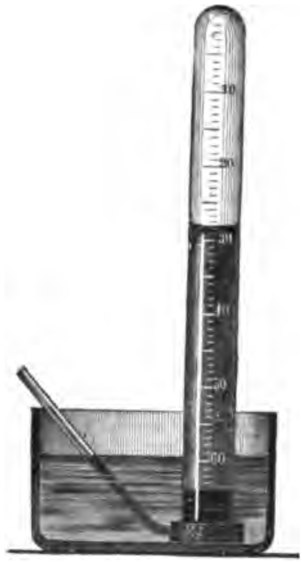


Fig. 107.

have shown that all gases are subject to the same amount of expansion for like changes of temperature, and that for each degree over or below 0° centigrade, the change in volume of the gases amounts to about $\frac{1}{273}$ of their volume of 0° C., or 32° Fahrenheit.

In measuring a certain volume of gas, it should therefore always be stated at what temperature and under what pressure the measurement has been made; and when several different

volumes are to be compared, the measurements ought either to be made at the same temperature and under the same pressure, or, as this often is not practicable, the result must be reduced by calculation, so as to render them comparable with each other.

It has, therefore, been agreed upon, in making these reductions, to adopt the temperature 0° C. and the barometrical pressure of 760 millimetres (30 inches) of mercury. If, therefore, we have measured the volume of inflammable gas originating from the decomposition of water at a temperature of $t°$ and a pressure of b millimetres, then we must, by calculation, find what the volume would have been at a temperature of 0° C. and barometrical pressure of 760 millimetres.

The quantities of inflammable gas obtained under the same conditions, the temperature and pressure being the same, by means of galvanic currents in the same length of time, are in proportion to the strengths of currents themselves.

In order to make the necessary corrections, we must first ascertain what the volume of gas would have been, measured at the temperature of $t°$ and a pressure of b mm., in case the pressure had been 760 mm. and the temperature 0°. Let us call the volume of gas measured at $t°$ V, and the volume of gas at 0° v_0, then for each degree of temperature the gas expands about $\frac{1}{273}$d part of the volume which it occupies at 0°; hence, for $t°$ the gas expands about $\frac{t}{273}$ part of its original volume at 0°; therefore volume v_0 for $t°$ temperature increase, expands about

$\frac{t}{273} \times v_0 = \frac{tv_0}{273}$; the true volume at $t°$:

$$V = v^0 + \frac{tv_0}{273} = \frac{273v_0 + tv^0}{273} = \frac{v^0(273+t)}{273},$$

and therefore the volume at

$$0° \text{ or } v^0 = \frac{273V}{273+t}$$

From the measured volume of gas V at b mm., we have, under the same pressure, volume v_0 at the temperature 0°. If, how-

ever, instead of b mm., the pressure were, for instance, 760 millimetres, then, according to Mariotte's laws, if we denote volume corresponding to 760 millimetres pressure by x, we have

$$x : v^0 = b : 760,$$

and from this

$$x = v_0, \frac{b}{760}$$

If we substitute the previously known value of v^0 in this equation, then we have

$$x = \frac{273 \, . \, V \, . \, b}{(273+t)\, 760}$$

In order to make this formula more clear by a numerical illustration, let us suppose that a certain current has developed in the voltametre 30.8 cubic centimetres inflammable gas per minute, at a temperature 15° C., and a pressure of 740 millimetres. To reduce this volume to 0° C, and 760 millimetres, we have to substitute in the preceding formula

$$V = 30.8, \; b = 740, \; t = 15,$$

from which we have

$$x = \frac{273 \, . \, 30{,}8, \, . \, 240}{(273 + 15)\, 760} = 28.43 \text{ cubic centimetres.}$$

That is to say, the current would have developed 28.43 cubic centimetres inflammable gas in one minute, at a temperature of 0°, and a pressure of 760 millimetres.

THE UNIT OF MEASUREMENT.

Measurement is simply the comparison of an unknown quantity with a known quantity of the same kind. In order, therefore, to measure the quantity of a galvanic current it becomes an absolute necessity to adopt a known current, the strength of which forms a unit of comparison by which to measure other currents.

Among the several methods proposed for measuring the

strength of currents, the unit employed by Jacobi deserves the preference, on account of its simplicity and clearness.

According to Jacobi, the unit strength of current is that which in one minute evolves 1 cubic centimetre inflammable gas at a temperature of 0° C., and a pressure of 760 millimetres; consequently, if any current gives in one minute a volume of *a* cubic centimetres inflammable gas, its strength is *a*, because the quantity of water which the latter has decomposed is always proportional to the volume of the inflammable gas evolved.

MEASUREMENT OF THE CURRENT STRENGTH BY MEANS OF THE VOLTAMETER.

In order to measure the strength of a galvanic current by means of a voltameter, it is only necessary to insert the latter into the circuit and mark the time by the watch. When we have a sufficient quantity of gas, then we interrupt the current, note the time during which the circuit has been closed, and measure the volume of gas obtained. If the temperature was not 0° and the pressure not 760 millimetres, then the necessary corrections of the volume of gas should be made.

We may easily find, by dividing the reduced volume by the number of minutes which have elapsed, how many cubic centimetres of inflammable gas at 0° C. and 760 millimetres pressure, the current has given per minute, and this number at the same time denotes the strength of the current itself—that is to say, it indicates how many times stronger this current is than one which gives one cubic centimetre of gas of the same density per minute. Accordingly, it follows that the strength of such a current, which gives in one minute 30.8 cubic centimetre of gas at 15° C. and 740 millimetres pressure, becomes, after reduction, 28.43.

Although the manipulation of the voltameter is apparently very easy, it is nevertheless not always available to measure the strength of currents, because weak currents decompose the water so slowly that it would require altogether too much time to obtain a measurable volume of gas, and the current during

such a length of time would perceptibly change its strength. On the other hand, the liquid in the voltameter opposes considerable resistance to the passage of the electricity and weakens the current. For this reason the quantity of gas obtained indicates the force of the current which has actually passed through the voltameter, and not the strength which the current from the same source would have possessed if it had not been made to pass through the voltameter.

MEASUREMENT OF THE STRENGTH OF CURRENT BY MEANS OF THE TANGENT OR SINE GALVANOMETER.

The resistance which the coil of the tangent galvanometer opposes to the passage of the current is so small in comparison to that of the voltameter, that it may almost always be included in the circuit without perceptibly diminishing the current. On the other hand, in these instruments, the indications of the needle depend upon the diameter of the coil, and therefore the same strengths of current on different instruments give different angles of deflection. The same instrument, when the strength of current is the same, will also give unequal deflections of the needle at different places upon the earth's surface, because the intensity of the magnetic power of the earth (the horizontal component of which always tends to carry the needle back to the magnetic meridian) varies upon different parts of the globe. Nevertheless it is easy, by carefully comparing the indications of the tangent galvanometer with a voltameter, to ascertain their relative value.

In order to compare the indications of the tangent galvanometer with the results of the voltameter, we must insert both a galvanometer and a voltameter in the circuit of a battery of several elements, and observe both the angle of deflection of the needle and the number of cubic centimetres of inflammable gas which the voltameter produces in one minute. Suppose this current has a strength of S, and produces in one minute a cubic centimetres of inflammable gas (at 0° C. and 760 millimetres pressure), and produces upon the galvanometer an angle of

deflection of $\alpha°$; now, we have another current of unknown strength x, which is to be measured, which gives upon the tangent galvanometer the deflection $\varphi°$; it is required to find how much inflammable gas the same would have produced in one minute.

In the first place the strengths of the currents are in the same proportion as the tangents of the angles of deflection of the tangent galvanometer; hence, is

$$S : x = \text{tang. } \alpha : \text{tang. } \varphi.$$

Then the strength of the currents is likewise in proportion to the volumes of the inflammable gas formed in one minute; hence, also, when we compare S with the current unit,

$$1 : S = 1 : a,$$

the multiplication of both proportions gives directly

$$1 : x = \text{tang. } \alpha : a \text{ tang. } \varphi;$$

hence the strength of current will be

$$x = \left(\frac{a}{\text{tang. } \alpha}\right) \text{tang. } \varphi;$$

a and tang. α, however, are the two known values. If we indicate this quotient

$$\frac{a}{\text{tang. } \alpha}$$

(which evidently indicates the gas volume corresponding with tangent 1) by z, then we get

$$x = z. \text{ tang. } \varphi;$$

that is to say, to make use of a tangent galvanometer for measuring currents, we must cause any convenient current to pass through its coil, and at the same time through a voltameter, and observe accurately the angle of deflection (α) and the quantity of inflammable gas (u) reduced to 0° C. and 760 millimetres; divide the latter (a) by the mathematical tangent of the angle (tang. α), then, once for all, we have in this quotient what is called the reduction factor or multiplier z of that particular galvanometer by which the tangents of the angle of deflection

produced by any other current should be multiplied in order to ascertain the strength of this current expressed in Jacobi's units.

Another example will further illustrate this:

The galvanic current from four elements gave, upon a tangent galvanometer, an angle of deflection of $\alpha = 18\frac{3}{4}°$, and in 3 minutes a volume of 78 cubic centimetres of inflammable gas. The temperature of the room was 15° C. and the height of the barometer 740 millimetres. The gas was caught over water in the graduated tube (fig. 107), and the surface of the water stood 10 centimetres higher inside the tube than outside. First of all the volume of gas is to be reduced from 78 cubic centimetres to 0° C. and 760 millimetres pressure. As 760 millimetres of mercury is equal to the pressure of $13.5 \times 760 = 10260$ millimetres of water, so 10 centimetres or 100 millimetres of water are equal to 7 millimetres of mercury. Hence the gas stood under a pressure of 740 mm. — 7 mm. = 733 mm. mercury. The same gas would, at 0° C. and 760 millimetres, occupy a volume of

$$x = \frac{273 \cdot 78 \cdot 733}{(273 + 15)\, 760} = 71.3 \text{ cubic centimetres.}$$

Hence, in one minute, the current evolved

$$\frac{71.3}{3} = 23.77$$

cubic centimetres of inflammable gas.

The tangent of $18\frac{3}{4}°$, the angle of deflection, is equal to 0.3394, consequently the multiplier of the galvanometer

$$\frac{a}{\text{tang. } \alpha} = \frac{23.77}{0.3394} = 70.003 \text{ or full } 70.$$

We must now multiply by this figure the tangents of the angle of deflection in order to find the strength of the current which causes the deflection. If, therefore, on this same galvanometer, at any time, a current gives an angle of deflection of 27°, then the strength of current will be

$$S = 70 . \text{tang. } 27° = 70 \times 0.5095 = 35{,}665\,;$$

that is to say, the latter is 35,665 times as great as that strength of current which develops in one minute 1 cubic centimetre of inflammable gas. Such a current, therefore, would produce in one minute 35,665 cubic centimetres of inflammable gas in the voltameter.

It must be understood that the reduction factor or multiplier of a tangent galvanometer must be ascertained with the utmost precision, and therefore should not be finally determined by a single experiment, but only after a series of experiments; the mean of the observations being taken as the true result.

If we wish to compare a tangent galvanometer whose reduction factor is yet unknown with another one whose factor is known, then we may pass any current at the same time through both galvanometers, and note the angle of deflection upon each. If this be denoted by α in the case of the known galvanometer, and its reduction factor be r, then we have for this the strength of current

$$S = r \text{ tang. } \alpha.$$

If the angle of deflection in the unknown galvanometer be ψ, and its unknown reduction factor x, then we have for this the same strength of current,

$$S = x \text{ tang. } \psi.$$

Hence, also,

$$x \text{ tang. } \psi = r \text{ tang. } \alpha,$$

and

$$x = \frac{r \text{ tang. } \alpha}{\text{tang. } \psi},$$

out of which immediately results the reduction factor of the unknown galvanometer.

It is evident, from what has been said, that the reduction factor or multiplier of a tangent galvanometer only answers for that particular instrument for which it has been calculated; the change which it undergoes when the instrument is carried to some other place is exceedingly small, as the intensity of the magnetism of the earth differs very little in different places.

In order to make use of a sine galvanometer to measure currents with a voltameter, the same method is employed.

CHAPTER XVI.

ELECTRICAL RESISTANCE.

The galvanic battery, or rather the electric current which is produced by it, is the vital principle of the electric telegraph. However varied may be the apparatus for the transmission of signals, in nearly every instance the galvanic battery is the origin of the force which is employed for this purpose.

In order to produce an electric current it is necessary to bring about a difference of electric potential in one or more bodies, or, in other words, a separation between the opposite electricities, and to provide a continuous chain or circuit of conductors, starting from the accumulating point of one electricity and returning to the accumulating point of the other electricity, through which path the equalization of the separated electricities may take place.

The force that gives rise to this electric tension is called electro-motive force, as before stated (page 86), and is usually indicated by E. The path through which the electricities reunite is called the line or circuit.

In every circuit the transfer or movement of the electricity is more or less impeded, and we therefore assume that the particles of different substances oppose a certain resistance to the passage of electricity, and this is called electrical resistance. The different metals oppose far less resistance to the passage of the current than do liquids; for example, copper is seven thousand million times as good a conductor as water. The amount of resistance offered to the current, as we shall see hereafter, also depends materially upon the length and sectional area of the conductor.

The electro-motive force tends to produce a certain quantity of electricity at the poles of the battery, this quantity depending

upon the nature of the particular metals and exciting solutions which have been placed in contact. When the circuit is completed the metallic conductors, and more especially the liquids which are included in the circuit, oppose the transfer of electricity; and the result of this is, that in a given time a quantity of electricity, varying according to the resistance of the circuit, will pass any given cross section of the latter.

In order, therefore, to overcome these resistances, the electricity must have a certain degree of potential energy, and the higher this potential is (it being the result of the electro-motive force), the more electricity will traverse the circuit while overcoming its resistance. It is evident, therefore, that the quantity of electricity which flows from a battery through any point in a circuit, during a given time, is limited by the resistance of the circuit, and that this resistance therefore may be employed as a measure of the strength of current.

UNITS OF RESISTANCE.

In order to be able to measure, compare, or express the different resistances with which an electric current meets in traversing a circuit, within the battery itself as well as exterior to it, we require a peculiar standard of measurement, which is called the unit of resistance. Unfortunately physicists have not yet been able to agree among themselves upon a common standard. Some of them have made use of a very thin copper wire of a certain length and sectional area, others have preferred to make use of wires of gold, silver, or alloys of different metals. The following are some of the principal units which have been thus made use of:

1. *Wheatstone's Unit.*—Professor Wheatstone constructed in 1840 the first instrument by means of which definite multiples of a resistance unit could be added to or subtracted from a given circuit at pleasure. The standard resistance unit which he proposed and employed was that of one foot of copper wire weighing 100 grains.

2. *Jacobi's Units.*—Professor Jacobi, of St. Petersburgh, has

suggested various units of electrical resistance. The unit commonly known as Jacobi's, and of which he sent copies to various physicists, was composed of twenty-five feet of a certain copper wire, weighing 345 grains.

3. *Siemens' Mercury Unit.*—This unit represents, according to the definition of Dr. Werner Siemens, the resistance of a prism of pure mercury 1 metre long and 1 square millimetre section, at a temperature of 0° centigrade. This unit was first produced in 1860, and resistance coils of German silver wire were copied from it.

4. *French and Swiss Units.*—In the telegraph administrations of France and Switzerland the unit of the resistance coils in use prior to 1867 was equivalent to the resistance of one kilometre of the iron wire employed for telegraph lines, of four millimetres diameter. As no very exact measurements of overhead lines are generally required, these units were neither defined nor produced with very great exactness, and no standard of temperature was given to enable the units to be reproduced when desirable. In 1867 these units were readjusted to equal 10 Siemens units, which is very nearly their original value. In French submarine cable work resistance coils adjusted to the Siemens unit are employed.

5. *Matthiessen's Unit.*—This unit was defined as the resistance of a statute mile of pure annealed copper wire $\frac{1}{16}$ of an inch in diameter, at 15.5° centigrade.

6. *Varley's Unit.*—This was formerly much used in England. It was originally constructed from a statute mile of special copper wire $\frac{1}{16}$ of an inch in diameter, but Mr. Varley afterwards readjusted it to 25 Siemens units.

7. *German Mile Unit.*—The first unit of measurement used in the Prussian telegraph service was that of a German mile (8,238 yards) of copper wire, its diameter being $\frac{1}{18}$ of an inch, and its temperature 20° Cent. Resistances adjusted to this unit were manufactured as early as 1848, but these have long since been superseded by coils adjusted to the mercury unit.

8. *American Mile Unit.*—The resistance coils used in the

United States prior to 1867, employed as a unit a resistance equal to that of one statute mile of No. 9 iron wire. These were prepared at the suggestion of Gen. M. Lefferts, then engineer of the American Telegraph Company, by Mr. G. M. Phelps, as early as 1862. The coils were of No. 36 iron wire, and arranged in sets of decimal numbers, so that the resistance could be read off directly without calculation. These have long since been entirely superseded by the British Association unit, or ohm.

9. *The British Association Unit.*—This unit was proposed in 1862 by Professor Weber, and his proposal was afterwards carried out with great care by a committee of the British Association for the Advancement of Science, in accordance with the suggestions of Professor Thomson. This unit is defined as equal to 10,000,000 $\frac{\text{metres}}{\text{seconds}}$. According to the most trustworthy determinations it is equal to 1.0486 Siemens mercury units.

Although all the above mentioned units have been employed to a greater or less extent, only two of them, viz., the British Association unit and the Siemens unit, are now employed to any extent for telegraphic measurements. The former is open to the objection of being very difficult of comprehension, and its reproduction, except by copying from a previously verified standard, is equally difficult, while the Siemens unit is of such a character that it may be produced at any time with comparatively little difficulty. The two units do not, in fact, differ very materially from each other, and in point of actual convenience in use there is little or no choice between them. For several years a lengthy and needlessly acrimonious discussion was carried on between the advocates of the two units, the final result of which has been the general adoption of the B. A. unit in England, and other countries where English is spoken, while the Siemens unit has come into general use on the continent of Europe. Practically, the B. A. unit or ohm may be said to be the recognized standard in use in America.

In order to be able to refer to the various resistances in the path of an electric current, in terms of one of the above men-

tioned units, and to express them in multiples or in fractions of the particular unit employed, we may imagine each portion of the circuit, such as the liquid in the battery, the porous cells, the iron wire of the line, etc., to be replaced by a standard wire, for example, a copper wire 1 square millimetre in sectional area, and of such length that it will oppose the same amount of resistance to the passage of the current as the portion of the circuit for which it has been substituted. The aggregate length of these standard wires will now represent the total resistance of the entire circuit, as we know by experience that the resistance of any wire of given dimensions and material is in proportion to its length.

The resistance of a portion of the circuit, or of the entire circuit, expressed by a certain length of the standard wire, is termed its reduced resistance, and the corresponding length of standard wire is termed its reduced length.

ELECTRICAL RESISTANCE OF METALLIC WIRES.

If we desire to find the resistance of any metallic wire, we may place it in the circuit of a constant battery, and observe the deflection of the needle of a galvanometer whose coils form a part of the same circuit. If we now remove the wire from the circuit, and replace it with such a length of the standard wire that the same degree of deflection is reproduced upon the galvanometer, the length of the standard wire thus interposed is a measure of the unknown resistance of the original wire.

Measurements or comparisons made in this manner by means of a tangent or sine galvanometer prove that the electrical reresistance of a metallic wire is directly in proportion to its length and inversely in proportion to its sectional area, or the square of its diameter. If the length of a wire be doubled or trebled its resistance is also doubled or trebled. If, therefore, a given wire, forming part of a circuit, is replaced by another of ten times its length and also of ten times its sectional area, the resistance will remain unchanged.

WIRE GAUGES.

Several different instruments are used for measuring the diameter of wires, which are termed wire gauges. The kind, perhaps, most generally used in the telegraph service, is known as the round wire gauge, and is shown of full size in fig. 108.

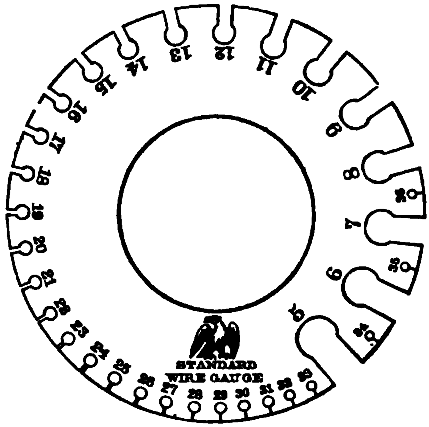


Fig. 108.

This is made from a tempered steel plate, and is provided with notches of graduated sizes around its periphery, corresponding with the different sizes of wire used in the telegraph service.

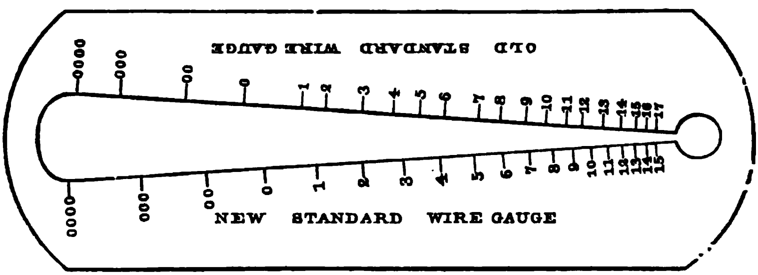


Fig. 109.

These different notches being marked by consecutive numbers, we speak in practice of No. 5 or No. 10 wire, &c. Fig. 109 is a pocket gauge, arranged upon a different plan, the wire being placed within the tapering opening. The figures at the side

indicate the number of the wire. The most accurate process of measurement is by means of the vernier caliper (fig. 110),

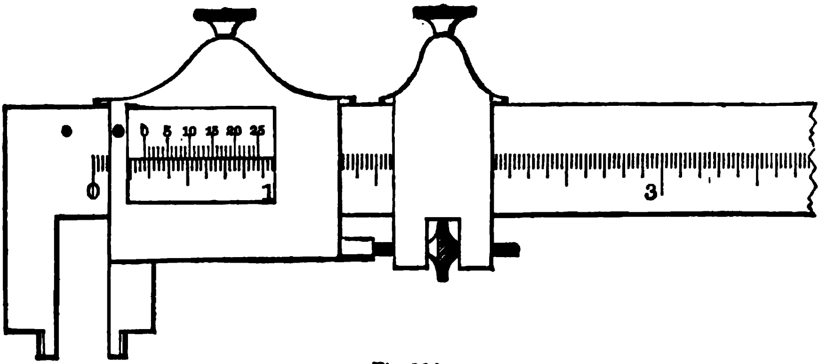


Fig. 110.

which gives the diameter of a wire to the thousandth part of an inch. More recently a pocket gauge has been introduced, which is shown full size in fig. 111, and will also measure the thickness

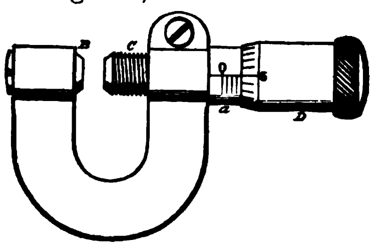


Fig. 111.

of wire or sheet metal to the thousandth part of an inch with perfect accuracy. Means of adjustment are provided in case of wear by continued use.

The lack of uniformity in the different wire gauges in use in this country and in Europe is a very serious evil. Wire purporting to be of a certain gauge or number, not infrequently will be found to differ several thousandths of an inch in actual diameter when furnished by different manufacturers.

At various times within the past few years practical men have called attention to the evils arising from the discrepancy

and want of uniformity in the common systems of wire gauges. Mr. Whitworth proposed, in 1857, the adoption of a gauge in which the number of each size corresponded to its diameter in thousandths of an inch. This was, however, too radical a reform to meet with general favor, and the proposed system never came into practical use. The following year Mr. Cocker proposed a new gauge, differing but little from those in ordinary use, but made more regular in its gradations. He also introduced the word "mil," to designate thousandths of an inch, which has been found very convenient in practice.

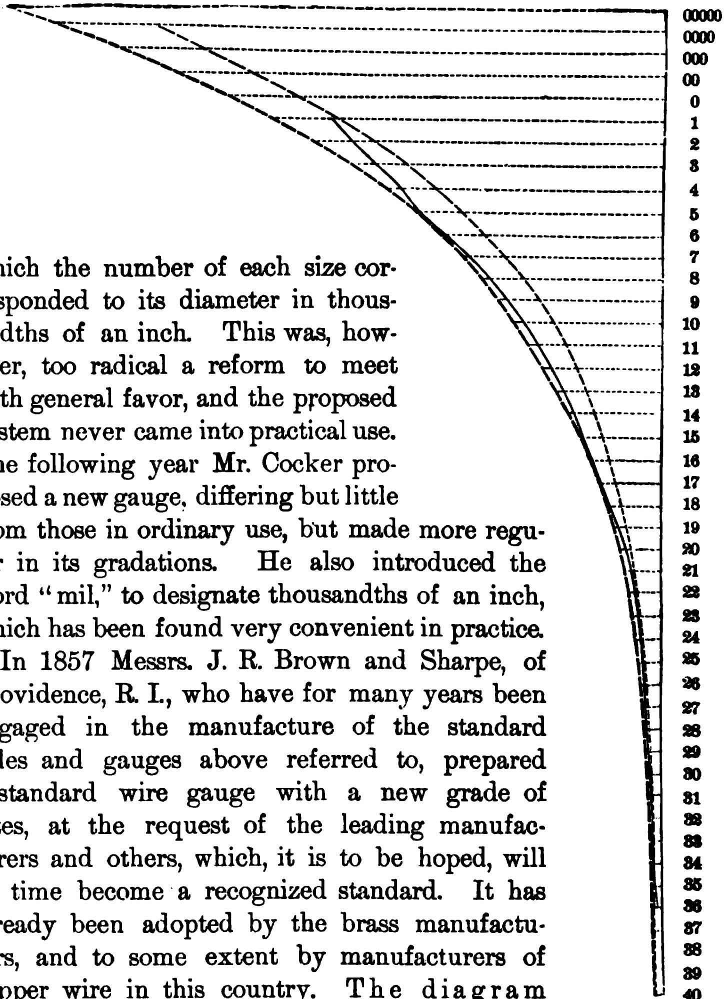


Fig. 112.

In 1857 Messrs. J. R. Brown and Sharpe, of Providence, R. I., who have for many years been engaged in the manufacture of the standard rules and gauges above referred to, prepared a standard wire gauge with a new grade of sizes, at the request of the leading manufacturers and others, which, it is to be hoped, will in time become a recognized standard. It has already been adopted by the brass manufacturers, and to some extent by manufacturers of copper wire in this country. The diagram (fig. 112) shows the curve formed by plotting out the different gradations to a scale, in which the full line shows the common or Birmingham gauge, the light dotted line the

American gauge, and the heavy dotted line a gauge proposed by Mr. L. Clark, in a paper read before the British Association in 1867.

In the American gauge the gradations are calculated as follows:

Let A = the first term in a geometrical series of numbers.
B = any other term whose number from A is N.
N = number of terms between A and B.
R = ratio or factor by which the terms are multiplied.

Therefore, if A = .005 in. or No. 36 gauge, B = .46 in. or No. 0000, and N = 40:

$$R = \sqrt[N-1]{\frac{B}{A}} = 0.0503536.$$

Each term, commencing with .005 or No. 36, being successively multiplied by this factor, gives the successive sizes, and any intermediate size may easily be found by calculation.

Table I in the Appendix gives the weight per lineal foot of the different sizes of wire by the American gauge, and also for the different metals in general use.

Table II shows the actual dimensions of the old and new gauges in decimals of an inch, and also the difference between consecutive sizes of each gauge.

In order to measure a wire it is passed into the angular opening of the gauge (fig. 109) till it touches both sides, the division at the point of contact indicating the number; thus it will be seen that No. 16 by the old gauge is almost exactly equivalent to No. 14 of the new.

The gauge proposed by Mr. Clark also starts from a given point, forming a logarithmic curve. The rate of increment for each succeeding number amounts to twenty-five per cent. on the weight of any unit of length of the preceding one, commencing with No. 16, which is assumed to be of the diameter of .065 in., as in the ordinary gauges.

Upon the first introduction of the electric telegraph in this

country the lines were constructed with No. 16 copper wire as a conductor, this size being more easily obtainable in large quantities than any other. It was afterwards found advisable to substitute iron wire in place of the copper which had been originally employed, as the former metal did not possess sufficient tenacity to withstand the strain to which it was exposed. As the specific conductivity of iron is less than one sixth that of copper, No. 9 was fixed upon as the size corresponding in conductivity with the copper wire before used, its sectional area being about five and a half times that of No. 16. Telegraphic constructors have continued to this day to use this size of wire in most cases in preference to any other, although, as above shown, its adoption was a purely accidental matter; and it has been thoroughly demonstrated that the use of a larger wire immensely improves the working of the lines.

The resistance which a metallic conductor opposes to the passage of the current depends not only upon its length and cross section, but upon the material of which it is composed. The conducting power of the different metals is by no means the same, and the greater the conducting power of any given metal the less is its resistance. If we take the resistance of copper as unity or 1, the resistance of a number of the best known metals under the same circumstances is as follows:

	According to Pouillet.		According to Riess.
Copper	1		1
Silver	0.73		0.67
Gold	0.97		—
Brass	3.57		3.95 (Müller.)
Platina	4.54		6.66
Iron	5.88		5.88
German Silver	15.47	Müller	11.33
Mercury	38.46		—

The discrepancies between the results of different experimenters can only be attributed to the fact that the degree of purity, toughness and density existing in a metal has considerable influence upon its specific resistance. It is also necessary to take the temperature into consideration, as the effect of heat

is to increase the resistance of metals. According to Müller, the resistance of an iron wire at a white heat is nearly 11 times as great as at the ordinary temperature of the atmosphere.

The resistance of metallic wires is increased by stretching them. The thinner the wire becomes, the greater is its proportionate resistance, if of iron, but if of copper, the contrary is the case. The resistance of an iron or copper wire is increased by rolling it into a spiral, and diminished by unrolling it. The resistance of a steel wire is increased almost one sixth by tempering it. The annealing of a hard drawn wire increases its resistance in all cases.

RHEOSTATS AND RESISTANCE COILS.

Rheostats and resistance coils are devices by means of which we are enabled to adjust or regulate at pleasure the amount of resistance in any given circuit. The construction and arrangement of the rheostat varies, it depending in a great measure upon the conditions under which it is intended to be used, whether for the insertion of large or small resistances into the circuit.

In cases where only a comparatively small resistance is required, and extreme accuracy of measurement is not absolutely essential, the apparatus known as Wheatstone's rheostat (fig. 113) is very convenient.

This apparatus is composed of two cylinders, G C, the one of metal, the other of wood or hard rubber, and of exactly the same diameter. These are so arranged that a very fine German silver wire of about $\frac{1}{100}$ inch diameter can be rolled and unrolled alternately from one to the other, the resistance of this wire being previously known. In order that the turns of the wire when rolled upon the non-conducting cylinder G may be well separated from each other, the cylinder is surrounded for its entire length by a fine screw thread, having 40 turns to the inch. An indicator placed at the extremity of the instrument, opposite the end of the cylinder G, or a graduated scale, E F, enables us to count not only the number of complete turns of wire made by

the cylinders, but even the fractions of turns. Finally, the apparatus is so constructed that when we turn one of the cylinders the other turns at the same time, so as to let the wire unroll on one cylinder as fast as it rolls up on the other. In order that the rheostat may be in good condition, the wire ought always to be kept tightly stretched between the cylinders.

To accompany this instrument there is required, first, a set of resistance coils, adjusted to the same unit as the wire of the rheostat; second, a sine or differential galvanometer. With these accessories the use of this apparatus is easy to understand.

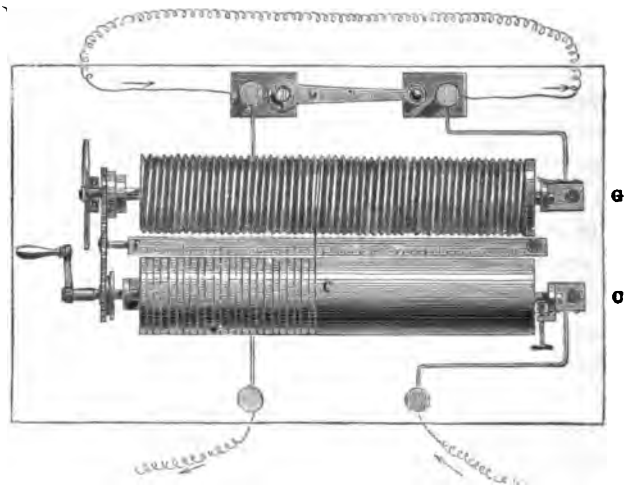


Fig. 113.

Suppose, for example, we wish to ascertain by means of the differential galvanometer the resistance of a piece of wire; the two extremities of this wire should be connected with the two poles of a battery, including in the circuit thus formed one of the wires of the differential galvanometer; from the poles of the same battery another circuit should be made, in which the wire of the rheostat and the second wire of the galvanometer are included. Care must be taken to arrange the connections in such a way that the two currents shall pass through the galvanometer in opposite directions.

When the rheostat is turned, so that all the German silver wire is rolled up on the metallic cylinder, it offers no appreciable resistance, and the needle of the galvanometer will be strongly deflected under the influence of the current which traverses the cylinder, because the second current is weakened by passing through the resistance of the wire which is to be measured; but if the German silver wire is gradually rolled up on the non-conducting cylinder, the first current is obliged to follow this wire in its convolutions around the insulating cylinder, and there is a certain point where the resistances of both circuits are precisely equal, one being weakened just as much as the other. This point is indicated when the needle of the galvanometer returns to zero. Then we stop the rheostat and read from the index the number of turns and fractions of turns marked there, which indicate the unknown resistance.

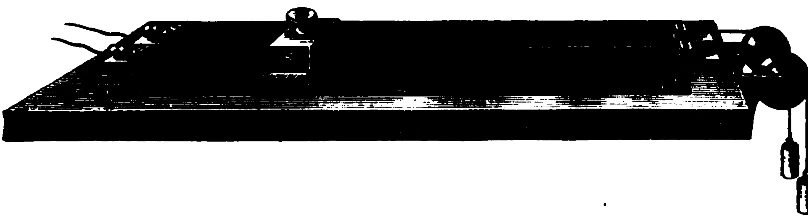


Fig. 114.

The wire of the rheostat usually contains a resistance equal to about ten miles of No. 8 iron wire, or one hundred and fifty ohms, but when the resistances to be measured are greater than this, additional resistance coils of known value are interposed into the circuit of the rheostat, and then the rheostat itself serves to make up the difference.

The principal objection to this form of rheostat consists in the fact that, after considerable use, the thin wire is liable to become bent or stretched, so that its resistance is more or less changed.

For making exact measurements of small resistances Poggendorff's Rheocord is admirably adapted. Fig. 114 will serve to illustrate the construction of the instrument.

Two platinum wires, *a b*, are stretched out on a board, and the

terminals of each clamped between two metallic plates; the termini of *a* by *c* and *e*, and those of *b* by *d f*. The terminals of *a* and *b*, after passing through the plates at *e* and *f*, are also attached to the silken strings passing over pulleys and fastened to weights. A brass measuring scale, *h i*, is placed under the wires, which are insulated from the metallic plates *c d* and *e f*. A slide, *k*, consisting of a small square metallic box, whose sides facing the clamps are composed of parallel plates of glass or ivory, moves up and down on the measuring scale. In the glass or ivory plates small holes are made, barely large enough for the wires to pass through. The box is filled with mercury.

When the clamps of *c d* are connected with the poles of a battery the current from *c* passes through the wire *a* to the box *k*, thence through the mercury which is contained in it to the wire *b*, and thence to the other pole. If the box is moved to the right the length of the connecting wire is increased, and if to the left, diminished. The measuring scale indicates the extent of the increase or decrease of the wire when the box is moved. Knowing the resistance of the German silver wire stretched between the clamps, as well as the resistance of every fractional division of it, the smallest subdivision of the wire may be employed as a unit of measurement for determining resistances, either by the differential or substitution methods.

When greater resistances are to be measured, standard resistance coils or rheostats made of German silver wire are employed. The most simple and effective arrangement of such a resistance apparatus is that represented by fig. 115. A series of short metallic

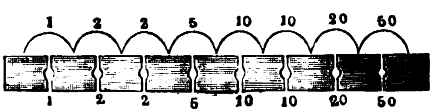


Fig. 115.

bars are placed at equal distances apart, upon an insulating slab, in such a manner that they can be connected together by means of brass plugs, inserted between them at pleasure. The brass bars are attached to the extremities of the coils of German silver wire

which compose the various resistances represented. If all the holes are plugged then resistance is inappreciable. If any hole is unplugged, then as many units of resistance are inserted in the circuit as are indicated by the number opposite the hole. By adding together the numbers unplugged we ascertain the total resistance inserted. The resistance coils are protected by being placed in a box, upon whose upper plate the binding screws for connecting the line and battery wires are placed, as represented

Fig. 116.

in fig. 116. When very great resistances are required rheostats are made as represented in fig. 117.

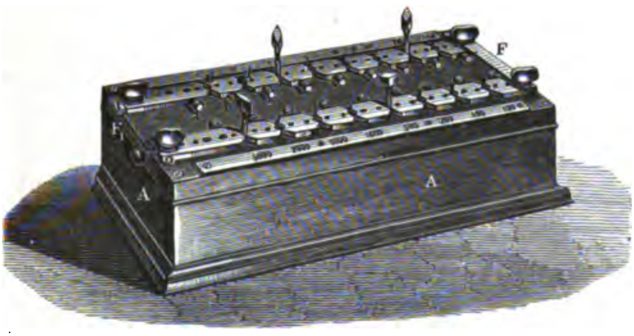


Fig. 117.

This is a combination of sixteen separate resistance coils, ranging from one ohm to five thousand ohms, securely enclosed in a mahogany or rosewood box, A. The extremities of resistance 1 are attached to the metallic plates *a* and *b*, those of the next resistance, 2, to *b* and *c*, and so on. When the holes between the clamps or metallic plates are unplugged, the respec-

tive resistances are inserted. The extremities of the wires to which the rheostat is to be connected are inserted in the binding screws 1 and 2. The metallic spring key, F_1, fixed at 1, can be connected with 2, and thus short circuit the resistance coils.

The different coils are in such proportions that any required number of units, from 1 to 10,000, may be unplugged at pleasure. When the holes are plugged, as represented in the cut, a resistance of 4,478 units is given.

In making a resistance coil care should be taken to wind one half of the coil in one direction and the other half in the opposite direction, in order to prevent induction. A current exerts an inductive action upon the wire through which it flows, called the induction of a current upon itself, the effect of which is to produce an induced current in the same wire at the moment that a current commences to flow through the coils, and another at the moment when the battery current is broken. By winding the coils as suggested this difficulty is prevented and the inductive effect is neutralized.

RESISTANCE OF LIQUIDS.

In order to determine the resistance of a liquid, a certain quantity of the liquid, of known dimensions, is placed in the circuit of a constant battery; it is then only necessary to ascertain what length of the standard wire or other unit gives the same resistance as the body of the liquid. It is self-evident that a

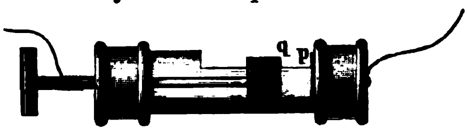


Fig. 118.

a process must be adopted by which all extraneous influences, such, for example, as galvanic polarization, are excluded. Such an arrangement has been devised by Wheatstone. His apparatus (fig. 118) consists of a glass tube about 2 inches long and $\frac{1}{8}$ inch inside diameter, which is open at the upper side for a length of $1\frac{1}{4}$ inches, while a cross section of 90 degrees, or one fourth

of the circumference, is ground away. At the right hand end in the figure is a metallic plug, which terminates in a platinum plate and is fixed hermetically in the tube; at the other end a piston, which likewise ends in a platinum plate. This is so arranged that it may be shoved up and down within it, and thus brought within $\frac{1}{4}$ of an inch of the stationary platinum plate, or removed to a distance of $1\frac{1}{4}$ inches therefrom. The piston, consequently, has exactly one inch stroke, and its movement, when required, may be easily measured by means of a micrometer screw.

In order to measure the resistance of a liquid with this apparatus, we first place it, together with a rheostat, a set of resistance coils and a galvanometer, in the circuit of a constant galvanic battery; then placing the piston at a distance of one fourth of an inch from the stationary platinum plate, the intermediate space between the piston and the platinum plate is filled with the liquid that is to be tested. By means of the rheostat the needle of the galvanometer is now brought to a certain point, the piston is then drawn back one inch and the intermediate space filled with the liquid. As the current has now to pass through a greater body of the liquid, it becomes somewhat weakened on account of the greater resistance, and the needle of the galvanometer is deflected less than at first. We again diminish the resistance by taking off rheostat turns, in order to bring the needle back, so as to reproduce the original deflection. When this has been done, then of course the resistance which has been taken out is equivalent to the resistance of an inch of the liquid tested, which may then be reduced to standard units without difficulty.

This apparatus shows conclusively that the resistance of any liquid is in direct proportion to its length, and in inverse proportion to its transverse sectional area. The conductivity of different liquids varies materially, and hence, each of them, like the different metals, has its own specific resistance.

The following table gives the relative resistances of a number of different liquids, that of silver being taken as unity or 1:

Sulphuric acid, specific gravity, 1.1	938,500
" " " 1.15	840,500
" " " 1.2	696,700
" " " 1.3	696,700
" " " 1.4	1,023,400
Chloride of sodium (saturated solution)	3,173,000
" sat. sol. diluted to twice its volume	4,333,000
" " " " three times "	5,721,000
" " " " four " "	7,864,000
Sulphate of zinc (saturated solution)	17,330,000
Sulphate of copper " "	18,450,000
" sat. sol., diluted to twice its volume	28.820,000
Nitric acid (commercial) 36° Baumé	1,606,000

We find from the preceding, that the specific resistance of liquids is much greater than that of solid conductors.

GALVANIC POLARIZATION.

When liquids are brought into direct contact with metals, and included in a galvanic circuit, they become decomposed by the action of the current, and this effect takes place even when the action is no longer visible to the eye. The component parts of the liquids, or, in other words, the products of decomposition, collect upon and cover the metallic surfaces which border the stratum of liquid, and thus a new electric difference or electromotive force arises between the metals, which tends to oppose the original electro-motive force of the battery. Metals which are thus affected in respect to their electro-motive force are said to be polarized, and the process is termed galvanic polarization. The effect begins at the moment the current first commences to pass through the liquid, and continues until it ceases to flow, and even for some time afterwards, especially if the current has been in action for a considerable length of time.

This may easily be demonstrated by connecting the platinum plates of a voltameter suddenly with the terminals of a galvanometer after a current has been passing between the plates for a considerable time. The needle of the galvanometer will be suddenly deflected, and the direction of its movement will show that the current is in a direction opposite to that of the original current by which the polarization was produced.

CHAPTER XVII.

OHM'S LAW AND ITS APPLICATION.

PRIOR to 1827 the ideas which were entertained regarding the propagation of electricity were exceedingly vague and indefinite. In consequence of its enormous velocity of transmission, it was thought to be analogous to light, and from the phenomena relating to the latter it was sought to deduce the laws governing the former. It was not until 1827 that the truth began to appear, in which year Ohm, a German mathematician, conceiving the idea that the propagation of electricity might well be similar to that of heat, applied to it the formulas which Fourrier and Poisson had deduced respecting the latter, and promulgated in a clear and precise manner the beautiful laws governing the transmission of electric currents which bear his name, the truth of which has been amply confirmed by experiment. The labors of Ohm did not, at first, receive in the scientific world the success which should have attended them, but on the contrary, subjected him to considerable persecution. It was not until ten years later, after M. Pouillet had arrived at the same results by experiment, that the scientists began to revise the judgment which they had formed against Ohm, and to appreciate the merits of his discovery. In the meantime, although adopting the formulas of the illustrious mathematician, the scientists have refused, until within the past few years, to admit his theory of the assimilation of the propagation of electricity to that of heat, and it is perhaps owing to this fact that they have arrived at such discordant results regarding the velocity of the electric current.

Towards the end of the year 1859, M. Gaugain, an able electrician, who had for some time occupied himself in verifying the laws of Ohm in regard to the transmission of electricity over

bad conductors, became convinced that electricity, instead of being propagated as a wave, or in a manner analogous to that of sound or light, was, on the contrary, as stated by Ohm, transmitted like heat in a metallic bar which is hot at one end and cold at the other. In this case the heat and the cold are communicated gradually from place to place, from the extremities of the bar, and in proportion as this double movement of heat and cold is propagated towards the middle of the bar, the parts first heated and cooled acquire and lose a quantity of heat until the two calorific movements having met each other, the different points in the bar lose on one side as much heat as they gain on the other. Thus a calorific equilibrium is established, and the distribution of heat upon all parts of the bar remains constant. This is what is called the permanent calorific state. But before a metallic bar arrives at this state more or less time is required, according to its calorific conductivity; and this time, during which every point of the heated body unceasingly changes in temperature, constitutes a variable period, which, if the assimilation of the propagation of heat with that of electricity is true, ought also to exist in the first moments of the transmission of a current; for, according to this hypothesis, an electric current is the result of the equilibrium which tends to establish itself throughout the circuit, between two different electric states constituted by the action of the battery, and representing, consequently, the two different temperatures of the heated bar. Without doubt, this variable period, by reason of the subtility of the electric fluid, must be exceedingly short; but upon very long circuits, and in transmission over poor conductors, it would be appreciable, and this is what the experiments of M. Gaugain have fully demonstrated. Since then he has investigated the laws of the transmission of the current during this variable period, and has established, among other laws, that the necessary time for a current to obtain the permanent state in a circuit—that is to say, all the strength which it is capable of acquiring—is proportional to the square of the length of the circuit. This result was not only foreseen by Ohm, but was mathematically formu-

lated by him in the equation representing the tension of the different points of the circuit in the variable period of the strength of the current. Thus Ohm, who was not a scientist, discovered, by force of reasoning, a phenomena which the electricians failed to discover until thirty-four years afterwards.

We shall presently state the laws of the current in the two periods of electric propagation, but it is first necessary to examine the distribution of the electricity in the circuit.

Let the ring (fig. 119) represent a homogeneous conductor, and a source of electricity be supposed to exist at A. The electricity from the point A will diffuse itself over both sides of the ring; the positive passing toward *a*, and the negative

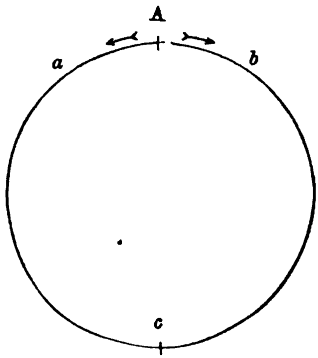


Fig. 119.

towards *b*, both fluids uniting at *c*. Now, if the electricity be uniformly distributed over the ring, it follows that equal quantities of electricity will pass through every cross-section of the ring in the same space of time. If it be assumed that the passage of the fluid from one cross-section to another is solely due to the difference of the electric potential at the two points, and further, that the quantity which passes is proportional to this difference of potential, it follows that the positive fluid proceeding from A right to *c*, and the negative fluid proceeding from A left to *c*, must decrease in potential the further they recede from A. The potential of the electricity at every point in the circuit may be represented by a diagram. Let the ring

be supposed stretched out into a straight line, A A′ fig. 120; let the ordinate A B represent the potential of the positive electricity, and A′ B′ the potential of the negative electricity, at the point of excitation, then the ring being homogeneous and of the same cross-section throughout, the straight line B B′ will express the potential for all points of the circuit.

From these considerations naturally follows the law of Ohm expressed by the celebrated formula $S = \frac{E}{R}$, where S represents the strength of the current, E the electro-motive force of the battery, and R the resistance. If the electro-motive force A B + A′B′ remains constant, then the greater the length of A A′ the less steep will be the inclination of the line B B′; that

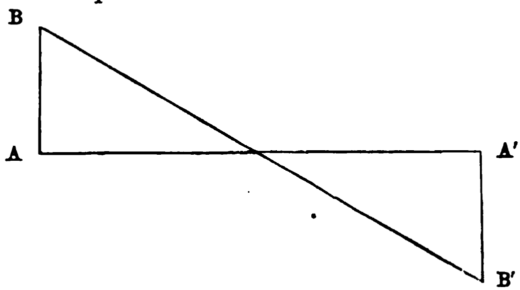


Fig. 120.

is to say, the less will be the difference of potential in two contiguous cross-sections. But by the hypothesis, this difference is proportional to the quantity of fluid which passes from one cross-section to another; and hence it follows that the greater the length of the circuit the less will be the amount of electricity which passes through any cross-section in a given space of time.

If the conductor A A′ be composed of material which offers a greater resistance to the passage of the electricity than that above supposed, as long as its length remains unaltered the distribution of the electricity will be the same. But inasmuch as the moving force—that is, the difference of potential between two neighboring cross-sections—is also the same as before, a less

quantity of electricity must pass from section to section in a given time than in the case of a good conductor; or, in other words, the current must be weaker. A greater length of the better conductor would produce precisely the same effect. These results find definite expression in the law that *the strength of the current is inversely proportional to the resistance of the circuit.* Preserving the length and material of A A″ unchanged, and regarding the force A A′ + B B′ as variable, we deduce the law that *the strength of the current is directly proportional to the electro-motive force.*

Let the conductor A A′ (fig. 121) consist of the same material throughout, but of two portions having different cross-sections. Let the cross section of Ad, for example, be m times that of dA′;

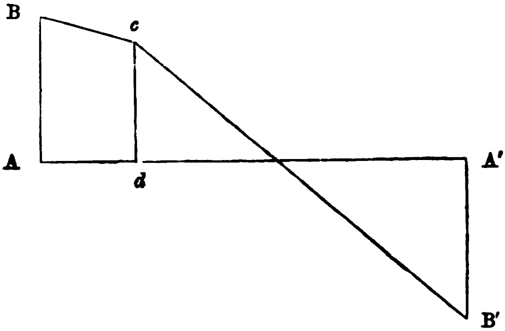


Fig. 121.

then, if equal quantities pass through all sections in equal times, if through a unit of length of wire of m times the cross-section no more fluid passes than through the thinner wire, the difference of tension at both ends of this unit of length in the former must be only $\frac{1}{m}$th of what it is in the latter. Thus the electrical fall, as Ohm terms it—that is, the decrease in the length of the ordinate for the unit of length of the abscissa—will be less in the case of the thick wire than of the thin, as shown by the line Bc in the figure. The distribution of the electricity in such a circuit will be no longer represented by a continuous gradient, but can nevertheless be easily ascertained by calculation when the electromotive force of the circuit and the cross-sections of its different

portions are known. If, instead of one wire being thinner than the other, its specific resistance were greater, it would follow from the hypothesis of Ohm that the greater the resistance of the metal the greater would be the electrical fall. The result is summed up in the law that *the electric fall is directly proportional to the specific resistances of the metals, and inversely as their cross-sections.*

To ascertain by experiment whether the actual distribution of electricity throughout a galvanic circuit bore any resemblance to that theorized by Ohm, M. Kohlrausch employed an electrometer of surpassing delicacy, consisting of a thin needle of silver wire, two inches in length, suspended horizontally from a glass fibre of exceeding fineness. The fibre, which passed in the usual manner through a glass tube, was fastened to a torsion head, the index of which being turned, caused the little needle of silver wire at the other end to follow it. The needle lay across a thin slip of silver of its own length, through a slit in the centre of which it could descend. At the slit the strip was bent right and left, so that the needle, in following the index, could lie its entire length against the strip. When the needle crossed the strip at right angles, the latter was raised so that the needle rested upon it, the apparatus thus forming a continuous cross of conducting material. Electricity being communicated to the strip, distributed itself over the entire cross. When this was effected, the strip was lowered so that the needle again hung free. The index above being turned, the needle was compelled by the torsion of the fibre to approach the strip, but being charged with a like electricity, was repelled. By this play of torsion on the one hand, and repulsion on the other, the potential of the electricity communicated was ascertained.

In connection with the electrometer a condenser was made use of, the accuracy of which was carefully tested beforehand. For experiments upon the galvanic circuit, both plates were of brass, suspended in a suitable frame by threads of silk, and separated from each other by shell-lac placed at three different points near the periphery. When the poles of the battery were

connected with these plates, one became charged with positive, and the other with negative electricity, and the strength of the charge was estimated by removing one of the plates to a certain fixed distance, and bringing the other, by means of an insulated copper wire, into connection with the electrometer. The question suggested itself to Kohlrausch, whether any relation existed between the electro-motive force of a voltaic element (which Ohm expresses in his formula by the letter E) and the tension of the electricity of the two poles of the element. The electromotive forces of various combinations were determined by Wheatstone's method. To ascertain the tension of the poles, the circuit, having remained in action for some time, was suddenly broken, and the ends of the wire were brought into connection with the plates of the condenser. The plates were then separated, and one of them immediately brought into connection with the electrometer, and the strength of the charge measured. The results derived from this process established the important fact that *the electro-motive force is proportional to the electric tension at the ends of the divided circuit.*

Ohm's law can be very easily proved experimentally by means of a tangent or sine galvanometer. In the first place it is clear that, if the electro-motive force remains the same, the strength of current, as measured by the galvanometer, will be inversely proportional to the resistance in the circuit, hence the deflections will decrease in proportion as the latter increase; and, secondly, with a constant resistance, the strength of current is directly proportional to the electro-motive force and increases with it; consequently, when the electro-motive force and the resistance are increased or decreased simultaneously, and in the same proportion, the strength of current remains unchanged.

In practice the preceding law possesses an unusual degree of applicability, in all calculations appertaining to galvanometric measurements and to the construction of galvanic apparatus. In further illustration of this law it seems advisable to offer an example here, viz., that of determining the influence which the number and the size of the elements have on the strength of current of a galvanic battery.

Suppose we take a closed circuit containing a simple voltaic element (for instance zinc and copper) and indicate its electromotive force by e, the resistance of the element itself by w, and that of the closing wire by l, then, according to Ohm's law, the current strength

$$s = \frac{e}{w + l} \quad . \quad . \quad . \quad \text{(I)}$$

If n such elements are connected up to form one battery and the circuit closed by the same wire as before, the electro-motive force of each element being e, that of the n elements will be $n\,e$; and the resistance of the battery will also be n times as great as that of a single element or $n\,w$; consequently, the strength of current s_1 of the battery will now be

$$s_1 = \frac{n\,e}{n\,w + l} \quad . \quad . \quad . \quad \text{(II)}$$

Now if the resistance l exterior to the battery is made infinitely small in comparison with the resistance w of the single element, which is the case when we use a short and very thick copper wire, then (because l in the denominator becomes nothing compared to w) we find from formula (I) the strength of current from a single element to be

$$s = \frac{e}{w}$$

and from (II) the strength of current from the entire battery consisting of n elements will be

$$s_1 = \frac{n\,e}{n\,w} = \frac{e}{w}$$

which shows us that in such a case the current from the entire battery is no stronger than that from a single element. If, on the contrary, as in the case of long telegraph lines, or multipliers having coils of very long and fine wire, the external resistance l is so great that the resistance w of the battery may be neglected in comparison with it, then we have, as the strength of current from a single element,

$$s = \frac{e}{l}$$

and, for the entire battery of n elements,

$$s_1 = \frac{n\,e}{l};$$

consequently, in this case, s_1 is n times as large as s; that is to say, the strength of the current increases in direct proportion to the number of elements.

Let us take another single element in which the surface of the plates (zinc and copper) is n times as great as the elements we have previously taken (I). In this case the greater surface of the plates has scarcely any perceptible influence upon the electro-motive force of the element, because this depends only on the nature of the metals employed, and on the liquids which are brought in contact with them. The electro-motive force of the element whose plates expose n times greater surface is, therefore, e also, while on the other hand the resistance of an element similarly arranged, and with the same distance between the plates, is no longer w, but varies as the sectional area of the liquid, which has become n times greater than in the former (I), consequently it is only $\frac{w}{n}$. If we make use of the same closing wire as at first, the strength of current of the n times larger single element is

$$s_2 = \frac{e}{\frac{w}{n} + l} = \frac{n\,e}{w + n\,l} \quad . \quad . \quad . \quad \text{(III)}$$

Now, should the resistance l of the closing wire be so small in comparison with the resistance of the element that we may, without sensible error, consider it null, then the strength of the current from the small element, according to (I), is

$$s = \frac{e}{w};$$

and the strength of the current from the element with n times larger plates, according to (III), is

$$s_2 = \frac{n\,e}{w};$$

which shows that the element with n times larger plates produces a current n times more powerful than the one with small plates.

Accordingly, when the resistance outside of the battery is very small, increasing the number of elements causes no increase of current, while, on the contrary, enlarging the plates causes a proportionate increase of current.

If, however, the resistance of the element is infinitely small compared with that external to it, then the current increases only by the number of elements being augmented, and not by the enlargement of the battery plates.

The preceding laws are completely confirmed by experiment with a tangent galvanometer, whose resistance in comparison with that of the element is so small that it may be neglected, and also by experiments on long telegraph lines.

If we divide the numerator and denominator of the fraction in equation (II) by n, then we get for stiength of current from a battery of n elements

$$s_1 = \frac{e}{w + \frac{l}{n}} .$$

If the resistance l is a constant one (for instance, 50 miles of line wire), the fraction $\frac{l}{n}$ becomes smaller as n increases, consequently the value s_1 corresponding to the entire fraction becomes larger. We find then, that with a constant resistance outside of the battery, the strength of current increases with the number of elements. As, however, $\frac{l}{n}$ continues to grow less, s_1 must continually approach the value $\frac{e}{w}$ without being able to reach or extend beyond it. It follows, therefore, that by simply increasing the number of elements we cannot always obtain any increased effect that may be desired, but that we may in every case approach a certain limit, represented by $\frac{e}{w}$ which a single

element gives when the resistance of the closing wire becomes infinitely small.

If to the total resistance W in a circuit, we add a new resistance W′, then the original current decreases; indicating this smaller current by S′ and the electro-motive force by E, we have

$$S = \frac{E}{W}$$

and

$$S' = \frac{E}{W + W'};$$

hence

$$S : S' = \frac{1}{W} : \frac{1}{W + W'}$$

or

$$S : S' = W + W' : W = 1 + \frac{W'}{W} : 1$$

If now W′ is very small compared to W, the fraction $\frac{W'}{W}$ is also small, and the value of $1 + \frac{W'}{W}$ becomes very nearly 1. In this case S and S′ are nearly equal, that is to say, when a current has already overcome a large resistance (W) then it will lose very little in strength if a new resistance (W′) is added, provided this resistance is so small that its value may be neglected in comparison with the former.

For instance, a relay or galvanometer placed in the circuit of a long telegraph line through which a current is passing, offers additional resistance to the current, but the greater the resistance of the line in comparison with that of the instrument interposed, the less is the current weakened. Conversely, however, the value $1 + \frac{W'}{W}$ differs more from 1, and consequently the difference between S and S′ becomes also greater, as W′ is large in comparison with W; that is to say, when in a given circuit a new resistance is interposed which is large in proportion to the former resistance, then the strength of the current is considerably weakened.

Hence, when we wish to make examinations or comparisons

of line resistances, for which, of course, such currents should be used as are most sensitive to differences in resistance, we should make use of a source of current having the smallest possible resistance of its own.

If we are to use a certain quantity of zinc and copper plate, or other material, for constructing a battery, we may require to know under what conditions the battery will give the most powerful current.

Suppose n equal elements are made from the material to be used. Call the electro-motive force of each E; the resistance of a battery of a single element containing the whole given material w, and the resistance of the closing wire l; then the metal surface in each of the n elements, supposing like thickness of plates, will be n times smaller, or $\frac{1}{n}$ of that in an element containing all the material. As the current in this case has to pass through n times smaller sectional area in each element than in an element with n times greater surface, the resistance in each element is n times greater than in the latter case, or $n\,w$; consequently for the n elements of the entire battery it is $n \times n\,w = n^2\,w$. Accordingly the strength of current from this battery,

$$S = \frac{n\mathrm{E}}{n^2 w + l} = \frac{\mathrm{E}}{nw + \frac{l}{n}}$$

This value of S is greatest for n when the denominator $nw + \frac{l}{n}$ is the smallest. If for this value of n we take another number n_1, so that $n_1 w + \frac{l}{n_1}$ is greater than $nw + \frac{l}{n}$ the difference of these two values

$$\left(n_1 w + \frac{l}{n_1}\right) - \left(nw + \frac{l}{n}\right),$$

or the expression equal to it

$$(n_1 - n)\,w + \left(\frac{1}{n_1} - \frac{1}{n}\right) l = (n_1 - n)\left(w - \frac{l}{nn_1}\right)$$

should always be positive.

Now, if $n_1 > n$, then the first factor of the last positive pro-

duct is positive, and therefore the second should be so, that is, $w > \frac{l}{nn_1}$. If, however, $n_1 < n$, the first factor $(n_1 - n)$ is negative, consequently the second factor of the positive product should also be negative or $w < \frac{l}{n\,n_1}$.

If now, starting from 0, we continually increase n_1 the fraction $\frac{l}{n\,n_1}$ grows smaller, whether the same fraction becomes $\frac{l}{n\,n_1} < w$ or $\frac{l}{n\,n_1} > w$, or whether we make $n_1 > n$ or $n_1 < n$, hence, if we take n_1 equal to n, then $\frac{l}{n\,n_1}$ should be neither smaller nor larger than w, but should be equal to it. Therefore, on the supposition that $n_1 = n$ when the above mentioned denominator $nw + \frac{l}{n}$ attains its least value,

$$\frac{l}{n\,n_1} = w,$$

or

$$\frac{l}{n_2} = w \text{ and } n^2 w = l,$$

In this case, however, the strength of current S is the greatest, and this shows that with a given quantity of material a battery produces the most powerful current when its own resistance is equal to that of the exterior circuit, or closing wire. Furthermore, it follows from what has been said, that $n = \sqrt{\frac{l}{w}}$; that is, if we wish to obtain the greatest strength of current, the battery must consist of as many elements as in whole numbers most nearly equal the value $\sqrt{\frac{l}{w}}$

We have already shown (page 88) that a certain number of elements may be connected with each other in different ways, either side by side in parallel circuits, or one after the other in series. If we indicate the resistance of one element by 1, then it is evident that the combination represented in fig. 122 is equal

to 8; in fig. 123 it would be equal to 4 in each series 1 to 4 and 5 to 8, when taken alone, but as the zinc and copper plates are connected in pairs, the sectional area of the liquid is twice as large, and therefore the resistance is only half as much as in fig. 122, consequently the resistance of the battery fig. 123 is equal to 2. In fig. 124 the resistance of each series, 1 and 2, 3 and 4, 5

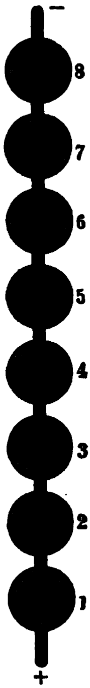


Fig. 122.

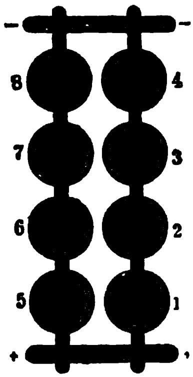


Fig. 123.

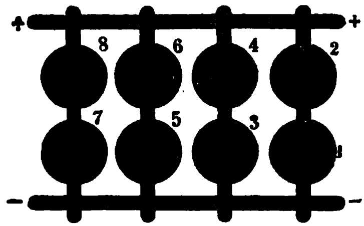


Fig. 124.

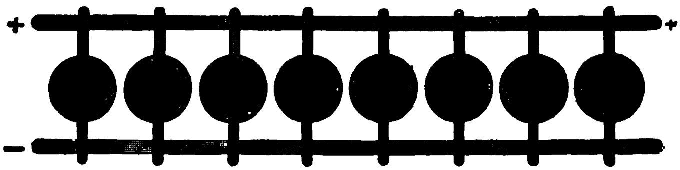


Fig. 125.

and 6, 7 and 8, is equal to 2, when considered separately, but the resistance of the battery taken as a whole is only $\frac{2}{4} = \frac{1}{2}$. For the same reason the resistance of the combination fig. 125 is only $\frac{1}{8}$.

Which of these combinations is to be preferred in any particular case depends upon the resistance of the closing wire. In all cases, however, that combination gives the strongest current in

which the resistance exterior to the battery, and that contained within it, differ least from each other.

The electro-motive force is not the same in the different combinations noticed above. If we indicate the electro-motive force of a single element by E, in the combination fig. 122, it would be 8 E in fig. 123, 4 E in fig. 124, 2 E in fig. 125, E.

Hence, if we call the strengths of current of the four combinations, S_1, S_2, S_3, S_4, the constant exterior resistance l, then the strengths of current for the single combinations are

$$S_1 = \frac{8\,E}{8 + l},\quad S_2 = \frac{4\,E}{2 + l},\quad S_3 = \frac{2\,E}{\frac{1}{2} + l},\quad S_4 = \frac{E}{\frac{1}{8} + l}.$$

If in each of these combinations in succession we make $l = 8$, $l = 2$, $l = \frac{1}{2}$, $l = \frac{1}{8}$, we at once find that the previously mentioned proposition is confirmed, as the combination gives in each case the greatest strength of current when l is equal to the battery resistance; when $l = 8$, then S_1 is greatest, when $l = 2$, S_2 is greatest; when $l = \frac{1}{2}$, S_3 is greatest; when $l = \frac{1}{8}$, S_4 is greatest.

If we wish to find how great the line resistance l must be in order that the combinations fig. 122 and fig. 125 shall produce equal strengths of current, we have only to make $S_1 = S_4$, whence

$$\frac{8\,E}{8 + l} = \frac{E}{\frac{1}{8} + l} \text{ or } l = 1.$$

In this case the strengths of current $S_1 = \frac{8}{9}$, $S_2 = 1\frac{1}{3}$, $S_3 = 1\frac{1}{3}$, $S_4 = \frac{8}{9}$, when we put $E = 1$.

We may also now easily ascertain which combination in a given case may be most properly used.

When we have n elements and the latter are so combined that a number of elements h are in series, and the number of such series g are arranged in parallel circuit, then $n = h\,g$.

If, therefore, we designate the resistance of one element by w, the resistance of each of the series alone is $h\,w$, and as the series g are connected parallel to each other, or as it is termed, in multiple arc, the resistance of the entire combination is $\frac{h\,w}{g}$.

Now, calling the resistance external to the battery l, the combination gives the largest current when the resistance of the battery is equal to l, hence we have in this case

$$l = \frac{h\,w}{g}$$

We have also seen that $n = h\,g$ or $g = \dfrac{n}{h}$

hence
$$l = \frac{h^2\,w}{n}.$$

or
$$h = \sqrt{\frac{n\,l}{w}}.$$

Now suppose we have, in figs. 122 to 125, 8 Bunsen elements at our disposal, in which the resistance of each element is 20 and the line resistance 40, substituting these values in the preceding formula

$$h = \sqrt{\frac{8 \times 40}{20}} = 4.$$

In this case the combination (fig. 123) of two rows, each containing 4 elements in series, will give the most powerful current.

In this case

$$S_2 = \frac{4\,E}{4 \times \dfrac{20}{2} + 40} = \frac{E}{20}$$

In the other cases (figs. 122, 124 and 125), when we designate the currents by S_1, S_3, S_4, as previously, we get

$$S_1 = \frac{8\,E}{8 \times 20 + 40} = \frac{E}{25}; \quad S_3 \frac{2\,E}{2 \times \dfrac{20}{4} + 40} = \frac{E}{25};$$

$$S_4 = \frac{E}{\dfrac{20}{8} + 40} = \frac{E}{42.5}$$

Therefore, the second combination (fig. 123) gives the strongest current; the last (fig. 125) gives the weakest.

If we wish to ascertain for what value of external resistance some one of the combinations, for instance that of fig. 125, will give a greater strength of current than the others, we have only to calculate the strength of the currents themselves.

Let the resistance of an element be equal to 20, as before, $E = 1$, then

$$S_1 = \frac{8}{8 \times 20 + l} = \frac{1}{20 + \frac{l}{8}}; \quad S_2 = \frac{4}{4 \times \frac{20}{2} + l} = \frac{1}{10 + \frac{l}{4}};$$

$$S_3 = \frac{2}{2 \times \frac{20}{4} + l} = \frac{1}{5 + \frac{l}{2}}; \quad S_4 = \frac{1}{\frac{20}{8} + l} = \frac{1}{2\frac{1}{2} + l}.$$

For the latter combination, S_4 becomes the largest when $l = 2\frac{1}{2}$; in this case this combination gives a stronger current than either of the other three; calculation confirms this, because then

$$S_1 = \frac{1}{20.3}; \quad S_2 = \frac{1}{10.6}; \quad S_3 = \frac{1}{6.2}; \quad S_4 = \frac{1}{5}.$$

CHAPTER XVIII.

THE LAWS OF BRANCH OR DERIVED CIRCUITS.

WHEN a wire is divided at a point A into two or more branches, which are afterwards united again at B, as is represented in fig. 126, the current is divided into as many parts as there are branches. If the branches are of equal length, and of the same material, the effect will be the same as if there was only one conductor of the same length, whose cross-section is equal to the total of the cross-sections of the separate branches. The quantity

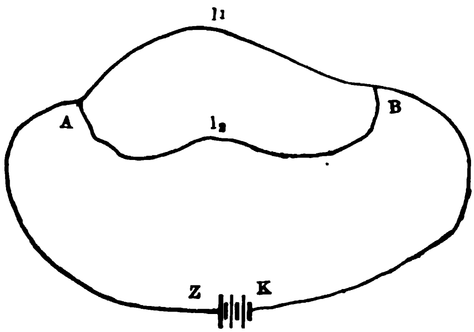


Fig. 126.

of electricity traversing each branch is, therefore, obviously in the same proportion to the total electricity circulating, as the sectional area of this branch is to the total sectional area of all the branches.

Suppose l_1 and l_2 be the reduced lengths of both lines which fork at A and B. Instead of these standard wires of unequal length, and of one square millimetre (·03937) sectional area, suppose they were of equal length; then it is obvious that these new wires, in order to retain the same conductibility, or to offer

the same resistance, must have smaller sectional areas in the proportion as they are shorter; for, when a wire is one sixth as long, and at the same time one sixth the sectional area of another, its resistance remains the same.

For the sake of simplicity let us take, instead of the lengths l_1 and l_2, wires of length 1, while we make them shorter relatively to l_1 and l_2; when, therefore, the resistances remain the same, the cross-sections must of course be smaller in the same proportion, and, therefore, become $\frac{1}{l_1}$ and $\frac{1}{l_2}$.

As now the two branches, l_1 and l_2, parallel to each other, taken together, are equivalent in conducting power to a single line, of the same conductivity and the same length, 1, but having a cross-section equal to the total cross-section of the two branches, we can use instead of it a single wire, which has the length 1 and the cross-section $\frac{1}{l^1} + \frac{1}{l_2} = \frac{l_1 + l_2}{l_1\, l_2}$, or of a wire, which, like the standard wire, has a cross-section of 1, and the length of which is

$$\frac{l_1\, l_2}{l_1 + l_2} \quad . \quad . \quad . \quad . \quad . \quad \text{(I)}$$

The last expression then, is the reduced length or the reduced resistance of both branch wires l_1 and l_2 taken together; it represents the length of a single standard wire of one millimetre cross-section, which can be used instead of both branches l_1 and l_2.

When between A and B a third wire is stretched, whose reduced length is l_3, the three branches, for the same reason, would give the same resistance as a single wire of length 1 and cross-section

$$\left(\frac{1}{l_1} + \frac{1}{l_2} + \frac{1}{l_3}\right) = \frac{l_2\, l_3 + l_1\, l_3 + l_1\, l_2}{l_1\, l_2\, l_3}$$

or a single wire of cross section 1, and length

$$\frac{l_1\, l_2\, l_3}{l_1\, l_2 + l_1\, l_3 + l_2\, l_3}$$

In order to find the strength of current in the undivided wire A Z or B K, as well in the branches between A and B, suppose the electro-motive force of the battery Z K to be E, its resistance and that of the undivided portion of the wire A Z K B to be w, then the strength of the current S is

$$\text{in A Z and B K}\dots\text{S} = \frac{\text{E}}{w + \dfrac{l_1\, l_2}{l_1 + l_2}}.$$

In A l_1 B and A l_2 B evidently passes the total strength of current S. The single branches, however, may, as we have seen, be replaced by wires of length 1 and cross-section $\frac{1}{l_1}$ and $\frac{1}{l_2}$, and both of them together by a wire of the length 1 and the cross-section $\frac{1}{l_1} + \frac{1}{l_2}$. Now the whole quantity of electricity circulating in Z A, which passes likewise through both branches l_1 and l_2, becomes divided between A l_1 B and A l_2 B in such a manner that one branch of two or three combined cross-sections also conducts two or three times as much electricity, and thus the branch with two or three times greater sectional area obtains also a strength of current two or three times as great. Hence we indicate, as heretofore, by S the total of current strength in A Z K B; and by S_1 and S_2 the strength of current in l_1 and l_2, respectively, then is

$$S_1 : S = \frac{1}{l_1} : \frac{1}{l_1} + \frac{1}{l_2},$$

or

$$S_1 : S = \frac{1}{l_1} : \frac{l_1 + l_2}{l_1\, l_2},$$

or

$$S_1 : S = l_2 : l_1 + l_2.$$

thus

$$S_1 = S \cdot \frac{l_2}{l_1 + l_2},$$

also,

$$S_2 = S \cdot \frac{l_1}{l_1 + l_2},$$

from which follows

$$S_1 : S_2 = l_2 : l_1, \qquad \text{(II)}$$

that is, the strengths of current in two branches are in inverse proportion to their reduced lengths or resistances; or, what is the same thing, a current always divides between two branches, in proportion to the respective conductivity of these branches.

The strength of current S in the undivided portion of the wire we have already found to be

$$S = \frac{E}{w + \frac{l_1 \, l_2}{l_1 + l_2}} = \frac{E(l_1 + l_2)}{wl_1 + wl_2 + l_1 \, l_2}$$

When we put this value in the latter two equations instead of S then, after reduction,

$$S_1 = \frac{E \, . \, l_2}{wl_1 + wl_2 + l_1 \, l_2}$$

$$S_2 = \frac{E \, . \, l_1}{wl_1 + wl_2 + l_1 \, l_2}$$

What has been said heretofore of two branches, of course applies equally well to several branches situated between the same points; for instance, by applying corresponding notation, we obtain in the case of three branches, for strength of current S_1 in branch l_1,

$$S_1 : S = \frac{1}{l_1} : \frac{1}{l_1} + \frac{1}{l_2} + \frac{1}{l_3}$$

and hence

$$S_1 = S \frac{l_2 \, l_3}{l_1 \, l_2 + l_1 \, l_3 + l_2 \, l_3}$$

WHEATSTONE'S BRIDGE OR BALANCE.

Wheatstone's Bridge gives an example of a peculiar distribution of the current. It was first used for the measurement of small resistances, to wit: when the resistance is considerable in the galvanometer circuit, the strength of current is changed so little by the addition of a small resistance that the difference causes a hardly perceptible movement of the needle, it is, therefore, required that the difference in current arising from slight

changes of resistance shall be indicated by the galvanometer without there being any considerable amount of resistance in the circuit.

Wheatstone, for this reason, suggested the following arrangement, which may also be very conveniently made use of to measure larger resistances, as we shall describe hereafter.

On a board of some 14 inches long and 4 inches wide (figs.

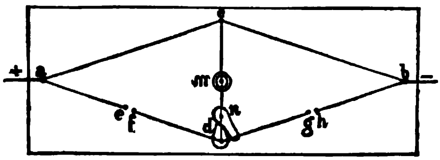


Fig. 127.

127 and 128) are placed four binding posts, *a*, *b*, *c* and *d*, in the form of a lozenge. Between *a* and *d* are placed binding posts *e*, *f*, and between *d* and *b* are placed binding posts *g* and *h*. These binding posts are, as is shown in fig. 127, connected by means of binding posts *a* and *b* with the poles of the battery; between *c* and *d* a multiplier or a galvanometer *m* is inserted.

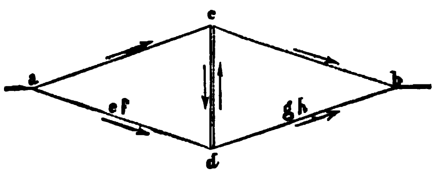


Fig. 128.

If between *e* and *f* and *g* and *h* wires are inserted, then the current branches off in various ways; here, however, only such parts of the current come into consideration as pass through the galvanometer *m*. One current passes in the direction *a c m d g h b*, as is indicated in fig. 128 by the full line; another part of the current goes in the direction *a e f d m c b* in an opposite direction through the galvanometer, as is shown by the dotted line. Now, if the resistance in both conducting lines *a c*

d b and *a d c b* are perfectly equal, then this is also the case with both parts of the currents passing in opposite directions through the galvanometer *m*, and hence the needle must remain at zero.

Now, if the length of the wire between *e* and *f* is changed but little, the resistance *a c d b* and *a d c b*, and consequently the two portions of current will no longer be equal, hence the difference of the currents must operate upon the needle, and will be the more perceptible as the sum of all the resistances is small, as a slight alteration of them will cause a decided movement.

In fig. 129 battery Z K is inserted, and the current branches off from A:

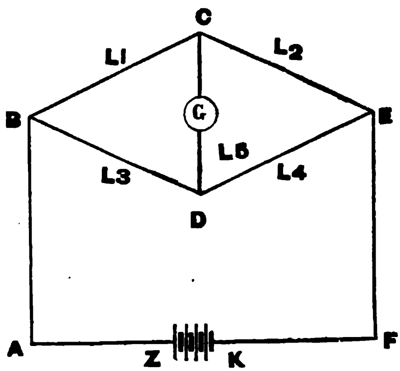


Fig. 129.

(1.) In the direction A B D C E F from D to C through galvanometer G.

(2.) In the direction A B C D E F from C to D through galvanometer G.

If, in consequence of these two currents moving in opposite directions through G, the needle of G remains in a state of rest, then the resistances of the sides B D C E and B C D E are necessarily equal to each other.

Now we find the reduced lengths of B C $= l_1$, of C E $= l_2$, of B D $= l_3$, of D E $= l_4$, of C D, inclusive of the galvanometer, $= l_5$.

If we consider B C and B D C to be two branches starting

from B, and uniting again in C, in which the current arriving at B becomes divided, so that after being united at C it flows towards C E, then the reduced resistance of both these currents B D C $= l_3 + l_5$ and B C $= l_1$.

$$\frac{(l_3 + l_5)\, l_1}{l_3 + l_5 + l_1}$$

We find the same resistance, when we consider B C D $=$ $l_1 + l_5$ as the first, and B D $= l_3$ as the second branch.

$$\frac{(l_1 + l_5)\, l_3}{l_1 + l_5 + l_3}$$

Hence the resistance of both combined branches and of wire C E $= l_2$ together

for current route, $\left.\begin{matrix}\text{B D C}\\ \text{B C}\end{matrix}\right\}$ C E.......... $\dfrac{(l_3 + l_5)\, l_1}{l_1 + l_3 + l_5} + l_2$

and

for current route, $\left.\begin{matrix}\text{B C D}\\ \text{B D}\end{matrix}\right\}$ D E.......... $\dfrac{(l_1 + l_5)\, l_3}{l_1 + l_3 + l_5} + l_4.$

These two last named resistances, however, should be equal to each other in case the needle G remains in a state of rest; hence, after removing the denominator,

$$l_2\, l_3 + l_1\, l_5 + l_1\, l_2 + l_2\, l_5 = l_1\, l_4 + l_3\, l_5 + l_3\, l_4 + l_4\, l_5 \quad . \ (a)$$

Likewise the resistances on routes B D $\left\{\begin{matrix}\text{D C E}\\ \text{D E}\end{matrix}\right\}$ to E and B C $\left\{\begin{matrix}\text{C D E}\\ \text{C E}\end{matrix}\right\}$ to E ought to be equal to each other; these resistances are relatively

$$l_3 + \frac{(l_5 + l_2)\, l_4}{l_5 + l_2 + l_4} \text{ and } l_1 + \frac{(l_5 + l_4)\, l_2}{l_5 + l_4 + l_2};$$

Hence, when we equalize the latter expressions, take away their denominators, and cancel some terms:

$$l_2\, l_3 - l_3\, l_5 - l_3\, l_4 - l_4\, l_5 = l_1\, l_4 - l_1\, l_5 - l_1\, l_2 - l_2\, l_5 \quad . \ (b)$$

If we add both equations we obtain

$$2\, l_2\, l_3 = 2\, l_1\, l_4$$

or

$$l_2\, l_3 = l_1\, l_4$$

or

$$\frac{l_2}{l_4} = \frac{l_1}{l_3}$$

After this it is evident that when the three resistances, l_1, l_2, l_4 are known, resistance l_3 can be easily found from the already known resistances,

$$l_3 = \frac{l_1 \cdot l_4}{l_2}.$$

Hence it follows, that in case the needle of the galvanometer remains at zero, the result will be, that the products of the opposite sides of the figure which the wires form on both sides of the needle are equal to each other.

KIRCHHOFF'S LAWS.

Kirchhoff is entitled to the credit of discovering the general laws by which every problem relating to the ramifications of electric currents can be solved. These laws, the result of an exhaustive mathematical study, are as follows:

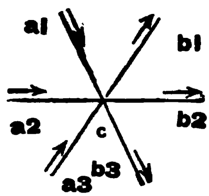


Fig. 130.

1. The sum of the current strengths in all those wires which converge to a point is equal to nothing. (The potentials of the currents which flow from this point have opposite signs from those flowing toward it.)

2. The sum of all the products of the currents and resistances in all the wires which form an enclosed figure is equal to the sum of all the electro-motive forces in the same circuit.

(All the potentials are to be indicated as positive ones, when the currents in the closed figure, according to their direction, keep up progressively the same direction; in the other case the forces of the opposite currents are to be taken as negative.)

The correctness of the first point is obvious from figure 130.

Suppose the intensities of the currents in the wires a_1, a_2, a_3, b_1, b_2, b_3, are successively indicated by S_1, S_2, S_3, S_4, S_5, S_6,

then we find, as the three first named currents flow towards point c and others flow from it,

$$S_1 + S_2 + S_3 - S_4 - S_5 - S_6 = 0.$$

If this were not the case, either the electricity must accumulate at point c, which would be contrary to all experience and to every conception of electricity in motion, or more electricity must flow from point c than flows towards it, which is obviously impossible.

The proof of the second law, owing to its generality, cannot be given in an elementary manner, except by a very minute and

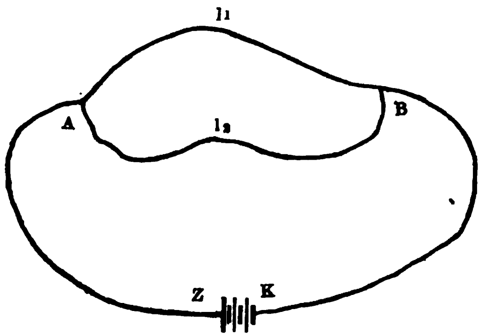


Fig. 131.

lengthy exposition. In order to demonstrate this fully we must refer to fig. 131.

If we represent the electro-motive motive force of battery Z K by E, the resistance in the undivided wire A Z B K, by w, the resistance in the branches by l_1 and l_2, the intensity in the undivided wire A Z K B by S, corresponding in the branch with S_1 and S_2, we find, according to law No. 2, in the closed figure Al_1 Bl_2, because these is no current in it,

$$S_1 . l_1 - S_2 . l_2 = 0 \text{..............................} (1)$$

In which the second product of the branch l_2 is taken negatively, as the direction of the current in this branch is contrary to the current of the first branch, which is flowing in the direc-

tion Al_1 B, and which, in the other instance, continually flows in the direction B l_2 A.

According to the same law, we find in the enclosed figure Z A l_1 B K:

$$S. w + S_1 . l_1 = E \qquad (2)$$

and in figure Z A l_2 B K

$$S. w + S_2 . l_2 = E \qquad (3)$$

A little calculation will plainly show the manner in which Kirchhoff's laws produce the same results, which we have already described:

$$S_1 . l_1 = S_2 . l_2, \text{ or } S_1 : S_2 = l_2 : l_1.$$

For point A, however, according to the law, we have:

$$S - S_1 - S_2 . = 0 \qquad (4)$$

When we take from (2) and (3) the value of S_1 and S_2, viz.:

$$S_1 = \frac{E - S . w}{l_1} \qquad (5) \text{ and } S_2 = \frac{E - S . w}{l_2} \qquad (6)$$

and substitute the same in the equation (4), then

$$S - \frac{E - S . w}{l_1} - \frac{E - S . w}{l_2} = 0$$

and hence

$$S = \frac{E (l_1 + l_2)}{w . l_1 + w . l_2 + l_1 l_2} \qquad (7)$$

When we put this value for S in the equations (5) and (6) we obtain

$$S_1 = \frac{E . l_2}{w l_1 + w l_2 + l_1 l_2} \text{ and } S_2 = \frac{E . l_1}{w l_1 + w l_2 + l_1 l_2} \qquad (8)$$

The flow of the currents in the different branches of Wheatstone's bridge may be demonstrated with equal clearness according to Kirchhoff's laws. If we indicate the resistance in the undivided wire E F K Z A B, in fig. 132 by w, the entire strength of current in this wire by s, the resistance in the wires BC, CE, BD, DE, CD by l_1, l_2, l_3, l_4, l_5, and the corresponding strengths of current in this wire by s_1 s_2 s_3 s_4 s_5, then will the strength of current in CD be indicated by g, according to the first law.

For point B $\quad s = s_1 + s_3 \ldots\ldots\ldots\ldots\ldots\ldots$(a)
" " E $\quad s = s_2 + s_4 \ldots\ldots\ldots\ldots\ldots\ldots$(b)
" " C $\quad g = s_1 - s_2 \ldots\ldots\ldots\ldots\ldots\ldots$(c)
" " D $\quad g = s_4 - s_3 \ldots\ldots\ldots\ldots\ldots\ldots$(d)

According to second law

in figure B C D $\quad g . l_5 = s_3\, l_3 - s_1\, l_1 \ldots\ldots\ldots$(e)
" " D C E $\quad g . l_5 = s_2\, l_2 - s_4\, l_4 \ldots\ldots\ldots$(f)

It follows from the equations (a) (b) (c) and (d)

$$s_3 = s_4 - g;\ s_1 = s - s_3 = s - s_4 + g:\ s_2 = s - s_4.$$

If, now, we substitute in these values (e) and (f) then

from (e) $g\, l_5 = l_3\,(s_4 - g) - l_1\,(s - s_4 + g)$
" (f) $g\, l_5 = l_2\,(s - s_4) - l_4\, s_4$

or,

$$g\, l_5 + g\, l_3 + s\, l_1 + g\, l_1 = s_4\,(l_3 + l_1)$$
$$- g\, l_5 + s\, l_2 = s_4\,(l_2 + l_4).$$

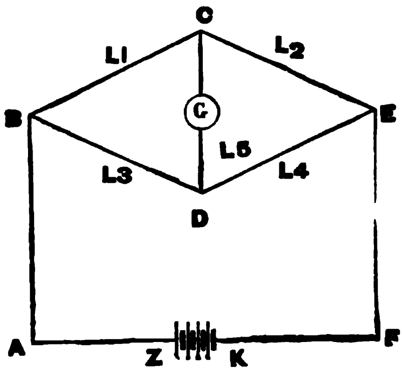


Fig. 132.

Now, if we divide both last named equations, and solve the new equation according to g, then we obtain, after reduction, this strength of current in wire C D, or in the galvanometer:

$$g = s\,\frac{l_2\, l_3 - l_1\, l_4}{l_5\,(l_1 + l_2 + l_3 + l_4) + (l_1 + l_3)\,(l_2 + l_4)} \ldots\ldots\ldots(g)$$

In case that, as in the practical use of the bridge, the current in the galvanometer is null, we get from (g)

$$l_2\, l_3 = l_1\, l_4$$

or,

$$l_3 = \frac{l_1\, l_4}{l_2}.$$

Bosscha's Laws.—Bosscha has published the following corollaries from Kirchhoff's laws, which very greatly simplify the calculation of branch currents.

1. If in any system of circuits containing any electro-motive forces there is a conductor in which the current = 0, the currents in the remaining circuits are not altered, if the circuit of the conductor in question is taken away together with the electro-motive force which is contained in it.

2. If the conductor in question contains no electro-motive force at all, then after it has has been withdrawn we may connect the terminal points m and n directly with each other, without changing by this means the remaining currents. If, on the contrary, it contains an electro-motive force, the points can only be joined again by inserting between them the equivalent electro-motive force.

3. If in a system of linear wires there are two wires, a and b, in which an electro-motive force in a produces no current at b, then the wire a may be divided without changing the intensity at b, and likewise without altering the intensity at a, the wire b may be divided.

SUPPLYING A NUMBER OF TELEGRAPH LINES FROM ONE BATTERY.

The method, formerly much in use, of supplying or working a number of telegraph lines from the same battery, depends upon the laws governing the distribution of electricity in branch circuits. We may, for instance, attach to the battery Z K, at the point A (see fig. 133), two separate circuits, the resistances of which, including that of the instruments included in them, are represented by l_1 and l_2. These lines are connected to the earth at E_1 and E_2.

It is evident that this is, in fact, precisely the same arrangement of circuits as that previously considered on page 202, and in fig. 126. The current going out from the point A divides into two branches which reunite at a common point, B (the earth), and the reunited current flows back to E and K, the earth playing the part of a conductor.

If we represent by S the strength of the undivided current in A Z K E B, and by W the resistance of the battery, and the current is supposed to pass simultaneously through both the circuits l_1 and l_2 then

$$S = \frac{E}{W + \frac{l_1 \, l_2}{l_1 + l_2}} \ldots\ldots\ldots\ldots\ldots\ldots (a)$$

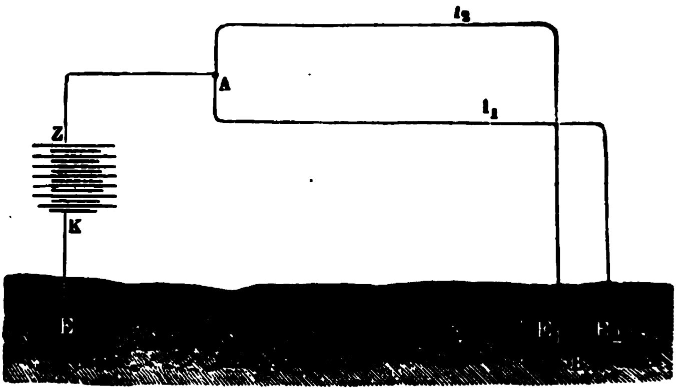


Fig. 133.

Now, assuming that the resistance W of the battery, in comparison with the sum of the resistances of all the branch conductors,

$$\frac{l_1 \, l_2}{l_1 + l_2}$$

is infinitely small, then we obtain for the aggregate strength of current in Z A : (*a*)

$$S = \frac{E}{\frac{l_1 \, l_2}{l_1 + l_2}}$$

or

$$E = S. \frac{l_1 \, l_2}{l_1 + l_2} \ldots\ldots\ldots\ldots\ldots\ldots (b)$$

Likewise, upon the same hypothesis, that the battery is closed

at the same time through both lines l_1 and l_2, the strength of current S_1 in the branch l_1 will be

$$S_1 = S.\frac{l_2}{l_1 + l_2} \text{........ ....(c)}$$

On the other hand, when the current of battery Z K is allowed to pass exclusively through line l_1 then the strength of current s_1, in line l_1, is

$$s_1 = \frac{E}{W + l_1};$$

or, because W in this case = 0,

$$s_1 = \frac{E}{l_1};$$

or, when we substitute the value of E from (b) in the latter equation,

$$s_1 = S\frac{l_1\ l_2}{l_1\ (l_1 + l_2)} = S.\frac{l_2}{l_1 + l_2}$$

therefore, by comparing the latter equation with the equation (c),

$$S_1 = s_1.$$

That is to say, when a number of lines are attached to one common battery, the internal resistance of the latter being infinitely small in comparison with that of the several lines or branch circuits, the strength of current in each circuit will be the same as if no other circuit was attached to the battery.

Under such circumstances, when several telegraph lines are connected with one common battery, it is immaterial whether one line alone is worked or whether several lines are operated at the same time. Although this fact may at first sight appear very singular, the explanation is, that while a single line is being supplied from a battery, and a second and third line are connected, the total amount of current flowing from the battery divides itself between the three lines, and in consequence of this the proportion of the total current traversing the former circuit becomes smaller than it was previously, but by connecting the two new lines the aggregate sectional area of conductor for discharging the battery increases, and so also does the strength of current in the same proportion, consequently the loss which

arises from the division of the current is exactly equaled by the gain resulting from the increased strength of current.

It was upon this principle that a large number of telegraph lines were formerly worked from a single Grove battery. The internal resistance of this battery is so small in proportion to that of a long telegraph line as to be almost inappreciable. For various reasons it has been found preferable to use batteries of greater internal resistance, and work but one or two wires from each one, and this latter arrangement is now generally adopted.

We have already shown that we derive the maximum strength of current from a given battery, when its internal resistance is equal to the resistance of the remainder of the circuit. Hence, when the latter is very great, as in the case of long telegraph lines, the internal resistance of the battery may also be considerable without materially affecting the strength of the current upon the line. For this reason almost all kinds of batteries, even the inconstant ones, are more or less adapted for working telegraph lines, and the longer the line—that is to say, the greater the resistance of the circuit—the better will such batteries answer the purpose. This, however, is the case only when each telegraph line has its separate battery. The result is very different as soon as the same battery is employed to work several lines; for in this case the resistance of the battery becomes an important part of the total resistance, and should therefore be limited to the smallest possible amount, for, as we have before stated, each line, whether one or more lines are working, should receive a current of equal strength. It follows, from these considerations, that the usual practice of increasing the number of elements in a common battery with the number of lines to be worked, is entirely wrong, because the total resistance of the battery is increased, and, consequently, the difference in the strength of current of each single line when closed by itself, or simultaneously with the others, increases also. For this reason inconstant elements (which have considerable resistance on account of the polarization of their plates), or very small elements, are not well adapted for a common or general battery. Assuming that

the internal resistance of the battery may be neglected in comparison with the joint resistance of the several branch lines, then each line will, under all circumstances, receive a current of the same strength as if the battery were closed through that line alone. As the number of elements, or the strength of the battery must necessarily be sufficient for the longest line attached to it, the strength of current in the shorter lines, when the difference of length is considerable, will be too great for the instruments in circuit. In order to reduce the strength of the current in the shorter lines to the required amount, we must either insert artificial resistances or else the unequal lines must not all be attached to the same point of the common battery. The shorter lines may preferably be attached to the battery in such a man-

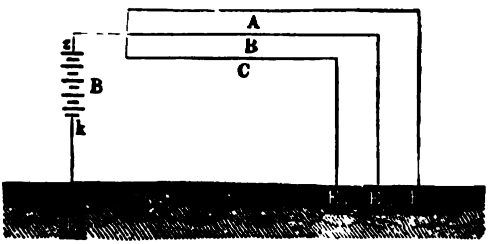


Fig. 134.

ner that the number of elements by which it is worked have the same relation to the length of the line as the whole number of elements have to the longest line.

Suppose that to a pole z of battery B (fig. 134), whose electromotive force of n elements is $n \times e$, and whose internal resistance is $n \times w$, are attached three lines, whose resistances are indicated by A B C. When the battery is closed by one of these lines the strength of current, according to Ohm's laws, is:

$$\left.\begin{array}{llll} \text{for A} & \ldots & s_1 = \dfrac{n\,e}{n\,w + \mathrm{A}} \\ \quad\text{B} & \ldots & s_2 = \dfrac{n\,e}{n\,w + \mathrm{B}} \\ \text{“}\ \ \text{C} & \ldots & s_3 = \dfrac{n\,e}{n\,w + \mathrm{C}} \end{array}\right\} \quad \ldots\ldots \quad (1)$$

If the three lines are closed simultaneously, so that the current traverses each line at the same time, the joint resistance of the three lines is

$$\frac{A\,B\,C}{A\,B + B\,C + A\,C}$$

and the current strength S in the undivided wire is:

$$S = \frac{n\,e}{n\,w + \dfrac{A\,B\,C}{A\,B + B\,C + A\,C}}$$

or,

$$S = \frac{n\,e\,(A\,B + B\,C + A\,C)}{n\,w\,(A\,B + B\,C + A\,C) + A\,B\,C}$$

whence the strength of current in each single branch is

$$\left.\begin{aligned} \text{in A} \,.\,.\, s' &= \frac{n\,e\,B\,C}{n\,w\,(A\,B + B\,C + A\,C) + A\,B\,C} \\ \text{in B} \,.\,.\, s'' &= \frac{n\,e\,A\,C}{n\,w\,(A\,B + B\,C + A\,C) + A\,B\,C} \\ \text{in C} \,.\,.\, s''' &= \frac{n\,e\,A\,B}{n\,w\,(A\,B + B\,C + A\,C) + A\,B\,C} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If we compare equations (1) and (2) we find the difference of the current strengths in each single line, when the current of the battery traverses the latter alone and the three lines simultaneously. This difference becomes less as w is made less—that is to say, the smaller the resistance of the battery the less this difference is, and it would disappear entirely if we could make $w = 0$; in this case the strengths of the currents given by equations (1) and (2) would be equal, that is, $s_1 = s'$, $s_2 = s''$, $s_3 = s'''$.

If the resistances A B C in the arrangement above mentioned (fig. 134) vary much, the current differences, $s_1 - s'$, $s_2 - s''$, $s_3 - s'''$, which we obtain when a line alone, or when all the lines are closed at the same time, become larger in the respective lines, and as each line requires from the battery only a strength of current proportionate to its resistance, lines differing in resistance, as we have said before, need not be joined to the same pole

of the battery. The shorter lines ought rather to be attached to the battery in such a manner that the number of elements which come into operation for the respective line stand in the same relation to the length of the line as the whole number of elements to the longest line.

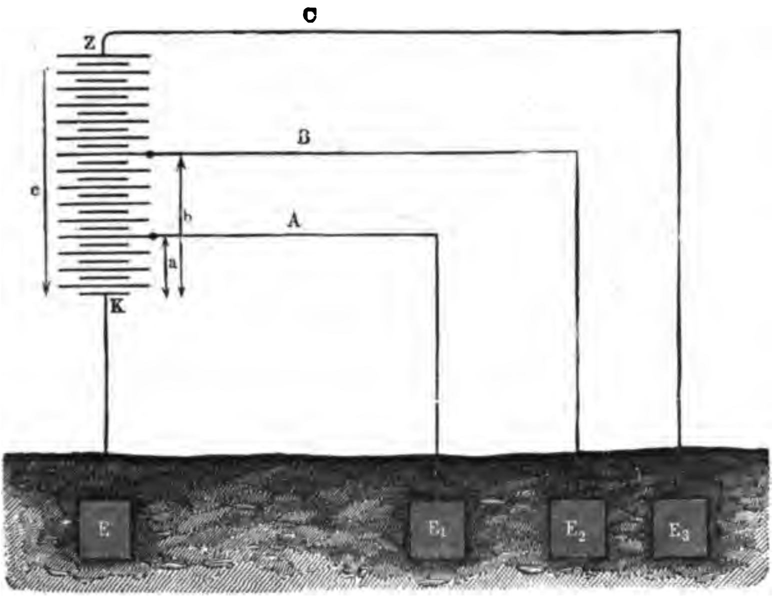


Fig. 135.

Hence, when, as in fig. 135, three lines A B C of unequal resistance are to be worked from one battery, Z K, the lines should be connected with the battery in such a manner that the relation is

$$\frac{A}{a} = \frac{B}{b} = \frac{C}{c}$$

where, as previously, the resistances of the single lines are indicated by A B C, and the number of elements by a b c, counted from the pole connected with the earth.

Now, if the resistance of an element is w and its electro-motive

force is e, the strength of the current, when each line is closed in succession, is

$$\left.\begin{aligned} &\text{in A} \ldots S_1 = \frac{e\,a}{w\,a + A} = \frac{e}{w + \frac{A}{a}} \\ &\text{in B} \ldots S_2 = \frac{e\,b}{w\,b + B} = \frac{e}{w + \frac{B}{b}} \\ &\text{in C} \ldots S_3 = \frac{e\,c}{w\,c + C} = \frac{e}{w + \frac{C}{c}} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

and as the relation of the number of elements in the battery to the resistance of lines is everywhere equal,

$$\left(\frac{A}{a} = \frac{B}{b} = \frac{C}{c},\right)$$

there circulates, relatively considered, an equally strong current in each line. When we may assume that the resistance of the battery and that of the earth are infinitely small, the strength of current in each line closed separately is no greater than it would be were all three lines closed simultaneously.

It follows from these considerations that a battery which serves to work several lines should have its internal resistance made as small as possible, and that the separate lines in the order of their respective resistances should be connected with a proportionate number of elements, so as to limit the differences of currents to so small an amount that they may be neglected in practice.

It remains to be mentioned that on lines subject to heavy escapes the use of one battery to supply several circuits has frequently proved unsuccessful, and has given rise to erroneous opinions. In consequence of the escapes by partial ground connection, the joint resistance of the several circuits becomes greatly reduced, and when a line on which there is considerable escape in proportion to its resistance, is attached to a battery supplying other wires, the proportion of the division of current is disturbed

in these wires, especially when the resistance of the affected wire is small. The difference of current in the good wires will vary in the same proportion as the escapes on the bad one.

When all the wires are not affected with escapes of nearly equal value in proportion to their length, the poorly insulated ones should be worked by separate batteries.

It has already been shown that, where several lines are worked from one battery, the strength of current in each line may also be brought nearly to correspond with its resistance by inserting artificial resistances and attaching the different lines to the same pole of the battery.

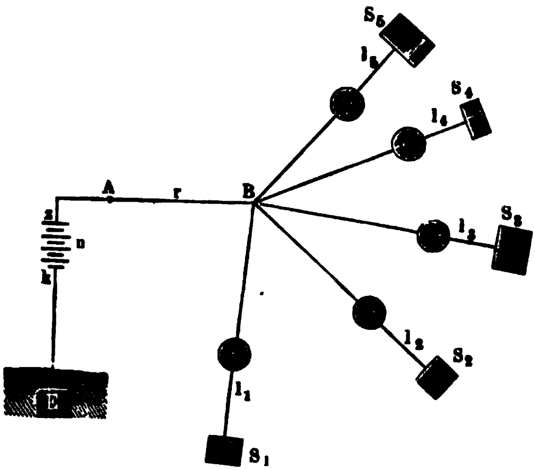


Fig. 136.

Suppose, in fig. 136 from point B, which is attached to the zinc pole of the battery Z K, of the central station A, five lines branching off to stations S_1, S_2, S_3, S_4 and S_5. Let n be the number of elements in the battery; w the resistance of a single element, e its electro-motive force, and r the resistance of the wire A B; also let l_1, l_2, l_3, l_4 and l_5 represent the respective resistances of the derived circuits branching off from B, including also the resistance of the instrument in circuit.

We, therefore, have for the joint resistance of the branch line from B:

$$Z = \frac{l_1\, l_2\, l_3\, l_4\, l_5}{l_1\, l_2\, l_3\, l_4 + l_1\, l_2\, l_3\, l_5 + l_1\, l_2\, l_4\, l_5 + l_1\, l_3\, l_4\, l_5 + l_2\, l_3\, l_4\, l_5}$$

and hence the total resistance W of the entire circuit of the battery.

$$W = n\,w + r + Z,$$

and the strength S of the current in the undivided wire A B,

$$S = \frac{n\,e}{W} = \frac{n\,e}{n\,w + r + Z}$$

Upon the same principle we obtain for the strengths s_1, s_2, s_3, s_4, s_5, of the currents traversing the different lines to the stations S_1, S_2, S_3, S_4 and S_5,

$$s_1 = S.\frac{l_2\, l_3\, l_4\, l_5}{l_1\, l_2\, l_3\, l_4 + l_1\, l_2\, l_3\, l_5 + l_1\, l_2\, l_4\, l_5 + l_1\, l_3\, l_4\, l_5 + l_2\, l_3\, l_4\, l_5}$$

$$s_2 = S.\frac{l_1\, l_3\, l_4\, l_5}{l_1\, l_2\, l_3\, l_4 + l_1\, l_2\, l_3\, l_5 + l_1\, l_2\, l_4\, l_5 + l_1\, l_3\, l_4\, l_5 + l_2\, l_3\, l_4\, l_5}$$

and in like manner we may ascertain the value for l_3, l_4 and l_5.

We at once see that the strengths of currents in the different lines are not equal, and that, in order to make them so, artificial resistances must be placed in the shorter circuits. As the main current at B divides itself in five branch currents, and as these currents are to have the same strength (it being assumed that the instruments at each station have the same resistance), the artificial resistance for each station must be of such an amount that by its addition the resistances l_1 . . . . . . l_5 become equal to each other, when it is obvious that

$$s_1 = s_2 = s_3 = s_4 = s_5$$

The longest line, for instance, S_5, does not need any additional resistance. If we indicate the resistance of the instruments by a, the artificial resistances to be inserted at S_1, S_2, S_3, S_4, by x_1, x_2, x_3, x_4, the resistances of the sections B S_1, B S_2,

B S_3,..........etc., less the resistance of the apparatus by L_1 L_2, etc.,

$$l_1 = l_2 = l_3 = l_4 = l_5$$

as . . . .
$$\begin{aligned} l_1 &= L_1 + a + x_1 \\ l_2 &= L_2 + a + x_2 \\ l_3 &= L_3 + a + x_3 \\ l_4 &= L_4 + a + x_4 \\ l_5 &= L_5 + a \end{aligned}$$

From which we may easily calculate the artificial resistance to be inserted at each station, namely:

$$x_1 = L_5 - L_1\,; \quad x_2 = L_5 - L_2\,;$$

and in like manner for the others.

The remaining formulæ for the resistance Z of the branch lines, as well as for that of the whole resistance W of the circuit, then become

$$Z = \frac{l_5}{5}\,; \text{ and } W = n\,.\,w + n + \frac{l_5}{5}.$$

Substituting these values in the above expression, we obtain:

$$S = \frac{n\,e}{n\,w + r + \frac{l_5}{5}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

also,

$$s_1 = s_2 = s_3 = s_4 = s_5 = \frac{S}{5},$$

or,

$$s_1 = s_2 = s_3 = s_4 = s_5 = \frac{n\,e}{5\,(n\,w + r) + l_5} \quad \ldots\ldots\ldots\ldots(2)$$

Now, in order to determine how many elements should be used to work the instruments in the branch circuits, when the currents are alike in all, we must find, by observation, what strength of current, under certain conditions, is required to work them. For instance, we know that under ordinary circumstances a Daniell's battery of 40 elements is sufficient to work a relay of 150 ohms on a line of 1,500 ohms' resistance. The strength S, of such a current, when e and w retain their former value, is

$$S_1 = \frac{40\,.\,e}{40\,.\,w + 1{,}650}$$

If now we call the resistance of a Daniells element two ohms, the current required to work the instrument is

$$S_1 = \frac{e}{43.25} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Adopting this value of S as the strength of current required in each of the five circuits S_1, S_2, S_3, S_4, S_5, we obtain from the equations (2) and (3)

$$\frac{n\,e}{5\,(n\,w + r) + l_5} = \frac{e}{43.25}$$

hence,

$$n\,(43.25 - 5\,w) = 5\,r + l_5$$

or, when $w = 2$ ohms,

$$n = \frac{5\,r + l_5}{33.25} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Now, suppose the resistance of the line A B is 500 ohms, and the line B S_5, 1,000 ohms, then, as the resistance of the instrument is 150 ohms, we have

$$r = 500,$$
$$l_5 = 1,150;$$

by substituting these values in equation (4) we finally obtain

$$n = \frac{5 \times 500 + 1,150}{33.25} = 109.77,$$

or, in round numbers,

$$n = 110.$$

Whence it follows, when we have made the resistances l_1 l_2 l_3 l_4 l_5 equal to each other, by inserting resistances at the different stations, and each is equal to $l_5 = 1,150$ ohms, that a battery of 110 Daniells elements at station A will supply simultaneously to each of the lines B S_1 B S_2 B S_3 B S_4 B S_5 currents of equal strength; each of which is strong enough to work the relays in the respective circuits.

The following will serve as a practical example of the manner in which problems relating to the supplying of several circuits

from one battery may be worked out without the aid of mathematics. We will suppose it is required to ascertain the difference in the strength of current on three wires, which are respectively 75, 100 and 150 miles in length when supplied by separate Grove batteries, of forty cells each, and by a single battery of the same size and kind.

If the three wires above mentioned were supplied from separate batteries of 40 cells each, the strength of current upon each would be as follows: Resistance of 75 miles of wire = 1,500 ohms; resistance of 40 cups of battery, 40 ohms. Total resistance, 1,540. Calling the electro-motive force 40,000, we have then $\frac{40000}{1540} = 25.98$ as the strength of current. The resistance of 100 miles of wire = 2,000 ohms; adding 40 for the battery, we have $\frac{40000}{2040} = 19.61$ as the strength of current. The resistance of the 150 miles of wire = 3,000 ohms; adding 40 for the battery, we have $\frac{40000}{3040} = 13.15$ as the strength of current.

In the above cases we have assumed that the wire was iron, of No. 9 gauge, having 20 ohms resistance per mile. If No. 8 iron wire were used, having a resistance of 14 ohms per mile, the strength of current from the same battery would be as follows:

$$75 \text{ miles}, \frac{40000}{1090} = 36.66; \quad 100 \text{ miles}, \frac{40000}{1440} = 27.77;$$

$$150 \text{ miles}, \frac{40000}{2140} = 18.69$$

If No. 4 wire were used, the strength of current with the same battery would be as follows:

$$\frac{40000}{640} = 62.5; \quad \frac{40000}{840} = 47.61; \quad \frac{40000}{1240} = 32.25.$$

When several wires are worked from one battery the problem as to the quantity of current upon each is somewhat more complicated. It is a case of branch circuits, and the question is what is the joint or combined resistance of the several branches? The following is the rule for finding this resistance:

Calling the resistance of one circuit R, and the other r, the joint resistance of any two circuits $= \frac{R \times r}{R + r}$, or the resistance equals the product divided by the sum. When the combined resistance of three or more branches is wanted, first find the joint resistance of any two of the circuits, and considering this as one resistance, combine it with the remaining one, and so on. For example, the resistance of the 75 mile wire is 1,500 ohms; the 100 mile wire, 2,000 ohms; and the 150 mile wire, 3,000 ohms. Thus we have, first, $\frac{1500 \times 2000}{1500 + 2000} = \frac{3000000}{3500} = 857$; and then $\frac{857 \times 3000}{857 + 3000} = \frac{2571000}{3857} = 666$, the combined or joint resistance of the three wires.

Another method of obtaining the joint resistance of several circuits is to add together their reciprocals, and the sum will be the reciprocal of their joint resistance. Thus, in the above case, the resistance is equal to

$$\frac{1}{\frac{1}{1500} + \frac{1}{2000} + \frac{1}{3000}} = \frac{1}{.000666 + .000500 + .000333} = \frac{1}{.001499} = 666.$$

If now we add to this the common resistance of the battery $r = 40$, the total resistance of the circuit will be $R + r = 706$, and the strength of current flowing from the battery, or generated by it, will be $S = \frac{40000}{706} = 56.65$. Now, this strength of circuit divides itself among the twelve branches in proportion to their several conductivities (conductivity is reciprocal of resistance).

Thus, the 75 mile wire gets 44.46 per cent. of the 56.65 = 25.18. The 100 mile wire gets 33.35 per cent. = 18.89, and the 150 mile wire gets 22.23 per cent. = 12.28.

The following table will show the comparative strengths of current upon three wires of 75, 100 and 150 miles in length, of No. 9 iron wire, when supplied from separate batteries of 40 cells each, and when supplied from a single battery of 40 cells:

Length of line.	Resistance of line.	Resistance of line increased by 40 (battery.)	Conductivity of wires.	Conductivity of wires, each decreased by 40 ohms.	Strength of cur't when supplied by separate batteries.	Strength of cur't when supplied from one battery of 50 cells.
75	1500	1540	.000666	.000642	25.98	25.18
100	2000	2040	.000500	.000490	19.61	18.89
150	3000	3040	.000333	.000328	13.15	12.58

Suppose a Grove battery of 85 cells is employed to work the following wires, viz: Eight wires, each 85 miles long and having respectively 7, 5, 3, 3, 4, 16, 33 and 7 relays; two wires of 200 miles in length, each having 33 and 34 relays, and two wires of 400 miles in length, each having 5 and 8 relays, what would be the strength of current upon each wire? What would be the strength of current upon each wire if they were supplied from separate batteries of 85 cells? What would be the strength of current upon each of the last four wires and the 85 mile line with 33 relays if they were worked from a single battery of 85 cells? What would be the strength of current upon the remaining wires if they were worked from a battery of 85 cells?

In order to answer the above inquiries accurately, it would be necessary to know the resistance of each wire and its relays; but assuming that the resistances of the relays are 200 ohms each, and the resistance of the wire is 20 ohms per mile, the following tables will give the required information:

TABLE A.

Number of line.	Resistance of line.	Resistance of line and relays.	Resistance of line and relays increased by 85 — battery.	Conductivity of wires.	Strength of cur't when supplied by separate batteries of 85 cells each.	Strength of current when supplied from one battery of 85 cells.
1	1700	3100	3185	.000322	26.68	21.62
2	1700	2700	2785	.000373	30.52	25.05
3	1700	2300	2385	.000434	35.64	29.37
4	1700	2300	2385	.000434	35.64	29.37
5	1700	2500	2585	.000400	32.88	26.92
6	1700	4900	4985	.000204	17.05	13.66
7	1700	8300	8385	.000121	10.13	8.16
8	1700	3100	3185	.000322	26.68	21.62
9	4000	10800	10885	.000092	7.80	6.12
10	4000	10600	10685	.000094	7.95	6.32
11	8000	9600	9685	.000104	8.77	6.93
12	8000	9000	9085	.000111	8.85	7.34

TABLE B.

Number of line.	Resistance of line.	Resistance of line and relays.	Resistance of line and relays increased by 85 — battery.	Conductivity of wires.	Strength of cur't when supplied by separate batteries of 55 cells.	Strength of cur't when supplied from one battery of 55 cells.
7	1700	8300	8355	.000121	6.58	6.41
9	4000	10800	10855	.000092	5.07	4.74
10	4000	10600	10655	.000094	5.16	5.02
11	8000	9600	9655	.000104	5.69	5.58
12	8000	9000	9055	.000111	6.07	5.85

TABLE C.

Number of line.	Resistance of line.	Resistance of line and relays.	Resistance of line and relays increased by 30 — battery.	Conductivity of wires.	Strength of cur't when supplied by separate battery of 30 cells.	Strength of cur't when supplied from one battery of 30 cells.
1	1700	3100	3130	.000322	9.58	9.04
2	1700	2700	2730	.000373	10.98	10.44
3	1700	2300	2330	.000434	12.87	12.12
4	1700	2300	2330	.000434	12.87	12.12
5	1700	2500	2530	.000400	11.85	11.55
6	1700	4900	4930	.000204	6.09	5 67
8	1700	3100	3130	.000322	9.58	8.97

By referring to the seventh column of table A it will be seen that No. 4 wire gets nearly five times as much current from the battery of 85 cells as No. 9; and table B shows that by dividing the wires and batteries as represented, No. 9 gets only 22 per cent. less current from 55 cells than it got from 85; or, in other words, the reduction of 35 per cent. in the number of cells would, under the circumstances, be followed by a reduction of only 22 per cent. in the strength of current.

Table C shows that the average strength of current on the seven wires mentioned, when worked from a 30 cell battery, is considerably greater than upon the five longer wires when worked from the 85 cell battery.

It is evident, of course, that if the strength of current is sufficient on 7, 9, 10, 11 and 12, when worked in common with the short wires from a general battery of 85 cells, as is shown in table A, then it is more than is required on 1, 2, 3, 4, 5 and 8 when supplied from a general battery of 30 cells, as shown in table C.

But the presence of a large quantity of electricity on a wire, or great strength of current, is not an essential element in working a telegraph line. Indeed, wires may be, and often are supplied from powerful batteries from which other wires are worked, but which, notwithstanding the large quantity of current obtained, are unable to work during rainy weather on account of the variation in the strength of current arising from the opening and closing of the circuits of the other wires.

The amount of attractive force which is exerted upon the armature of a relay is of far less consequence in the practical working of a line than the uniformity of the force.

It is the difference or margin of force acting upon the relay at the receiving station, when the key at the sending station is opened and closed, upon which the operator depends for his signals.

Now, suppose that during a very wet day the two stations situated at the extreme ends of wire No. 9—four hundred miles apart—were working upon a margin of 12 per cent. By reference to table A it will be seen that the strength of current upon

that wire from a battery of 85 cells would be 6.12 when the keys were closed on all the wires, and 7.80 when the keys on all the other wires were opened—for by opening the other eleven wires the battery is made a special one for the remaining wire—thus the simultaneous opening and closing of all the other circuits would affect the strength of current of this one 27 per cent. while the working margin was only 12 per cent. Of course the line could not be worked under such circumstances, although when supplied from a separate battery, or even from a battery which worked a less number of wires, it would meet with no difficulty. Take, for example, the same wire as represented in table B. When all the wires working from the general battery have their circuits closed, the strength of current on No. 9 would be 4.74. When the rest were open it would be 5.07, thus showing that only a difference of 7 per cent. would exist in this case against 27 in the other.

From the above it will be seen that the great waste of money in working many wires of all lengths out of one battery is not the most grievous loss, but that the injurious effects upon the practical working of the wires, especially during wet weather, far outweighs it. Few persons, we apprehend, really know how much of the trouble which arises from this great evil of working so many wires from one battery is erroneously attributed to bad insulation and other causes.

CHAPTER XIX.

THE MEASUREMENT OF RESISTANCES.

THE measurement of the resistance of a given length of wire or of a telegraph line may be performed by various methods, of which sometimes one and sometimes another may be preferable, this depending largely upon the instrument we desire to make use of for measuring purposes. The usual methods are the following:

THE METHOD OF SUBSTITUTION.

The most simple method of measurement is to include the resistance which is to be measured, together with the galvanometer, in the circuit of a galvanic battery, observe the deflection of the needle, and then replace the unknown resistance by another known resistance, for instance, a certain number of ohms or Siemens units, or by an adjustable rheostat, and then to so adjust the last named resistance that the deflection of the needle of the galvanometer is the same as before. The unknown resistance is of course equal to the known resistance by which it has been replaced.

But this method is seldom available in practice. If the resistance to be measured is very small, then a sensitive galvanometer will be deflected to an angle of nearly 90° and the polarity of the needle may even be reversed. If, on the other hand, we use an ordinary galvanometer, then the deflection changes but very little after the angle of deflection has reached 30 or 35 degrees. In addition to this, there is danger that the strength of the current may change during the time occupied in making the two measurements.

We may arrive at a more exact result by employing a differential galvanometer, G (fig. 137), which is provided with two

separate coils, $l\ m$ and $n\ p$, of equal power but opposite action. The binding screws, $m\ n$, are connected by means of the wires, $i\ q$, with one of the poles of the battery, S, while the other two binding screws, $l\ p$, are connected on one side with the screw o, and on the other side with a resistance coil or a rheostat, R. The other pole of the battery is connected with the binding screw o_1 as well as with the same rheostat, R.

Now, in order to determine the resistance of the wire A B C, we may connect the extreme end A to o, and C to o_1,

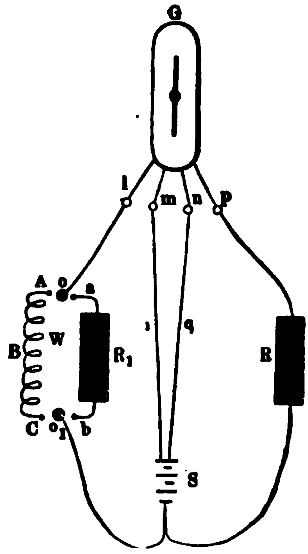


Fig. 137.

and adjust the resistance of the rheostat, R, so that the needle of the galvanometer will stand at zero. As the two opposing coils of the galvanometer are never exactly equal in their action upon the needle, the resistance of rheostat R is not, strictly speaking, equal to the resistance of the wire A B C.

We may, however, remove the wire A B C, and substitute therefor another rheostat, R_1, connecting a with o and b with o_1. If we now adjust the rheostat, R_1, so as to cause the needle to

return again to zero, then the resistance inserted by means of R_1, which we may read off on the instrument, is evidently equal to the unknown resistance of the wire A B C.

When one of the ends of the wire, for instance C, is connected with the earth, then we must also connect o_1 with the earth and proceed in the same manner as before. In this case, however, it is necessary to take into consideration the fact that the earth currents or currents of polarization may render the measurements inaccurate. The effects of the latter may be avoided by making the measurements very quickly, so as not to give the earth plates time to become polarized.

The preceding method is evidently not applicable in cases where the resistance, A B C, is so large that the rheostat wire required for its measurement is insufficient, and larger resistance coils are not available. Hence, it cannot be used to determine, for example, the resistance of the insulating coating of a submarine cable when the cable itself is only a few miles in length. This will be referred to hereafter in connection with the subject of submarine lines. It is only desired in this place to mention the general fact that, in cases of this kind, a galvanometer may be used which consists of two coils of opposite direction, but differing in respect to the number of convolutions in each coil. For example, one coil may have 100 turns and the other 1,000. In this case the former requires a current 10 times as strong as the latter to produce the same effect upon the needle. The resistance in the former coil should also be only one tenth that of the latter, the battery being the same for both coils.

It is true that the relation of the strength of current is not exactly in proportion to the number of convolutions in the galvanometer, as both coils have not exactly the same effect upon the needle; but, by means of a preliminary test, the relative strength of the two currents, which has an equal action upon the needle, may be easily determined.

Let g (fig. 137) represent the resistance of the coil situated between n and p, and g_1 that of the coil situated between l and m, and suppose two graduated rheostats, R and R_1 (removing A B

C) to be inserted in the two circuits, and so adjusted that the needle of the instrument stands at zero. If we indicate the resistances which are added by means of the rheostats by R and R_1, and the strengths of currents which flow in both circuits respectively by S and S_1, then the latter are in an inverse relation to the resistances $g + R$ and $g + R_1$, which we find in the circuits; hence we have

$$\frac{S}{S_1} = \frac{g_1 + R_1}{g + R}$$

If we replace the resistances R and R_1 by two others, r and r_1, then these would also cause no deflection of the needle, for the reason that the new strengths of current, s and s_1, stand in the same relation to each other as S and S_1. Now, however,

$$\frac{s}{s_1} = \frac{g_1 + r_1}{g + r};$$

hence no deviation of the needle takes place when

$$\frac{g_1 + r_1}{g + r} = \frac{g_1 + R_1}{g + R}$$

The latter relation, however, may be determined, once for all, by a preliminary test; we will call it the coefficient of the instrument and indicate it by K.

Now, in order to determine with the aid of such an instrument the resistance W, of line A B C, which is very considerable (fig. 137), we insert it between o and o_1, adjusting the rheostat R so that the needle in g will stand at zero. Now, if we indicate by ρ the resistance of rheostat R (which resistance we find in the right hand circuit), then we have, when the needle stands at zero,

$$\frac{g_1 + W}{g + \rho} = K$$

or

$$W = K(g + \rho) - g_1$$

Now K, g, g_1 and ρ are known resistances; hence, by them we are able to determine the resistance W of the line A B C.

In many cases, as for example when testing submarine cables, we may neglect the resistance of the galvanometer when its resistance is small in comparison with that of the circuit measured; we have then,

$$W = K \rho.$$

With this method, by which we may find the resistance sought by another 10, 100 or 1,000 times smaller, it is easy to exclude the influence of earth currents, which may appear when one end of the resistance to be measured terminates in a ground plate. To do this the battery is removed, and the wires i and q connected directly with each other and with o_1 and R, at the same time another earth connection is made at o_1. If an earth current is present, and deflects the needle of G, we have only to place a small steel magnet near G in such a manner that the needle again stands at zero, the influence of the earth current being thus compensated by the magnet. But even this is not strictly necessary; we may consider the degree over which the needle stands under the influence of the earth-current as zero mark, a position corresponding to the state of rest of the needle.

If the rheostat resistance is insufficient to determine the very considerable resistance to be measured, we may insert two batteries of unequal strength but of like elements in both circuits. If we place one battery, whose current circulates in the smaller coil of the galvanometer and of the rheostat—for instance 10 elements—and the other battery, in whose circuit is included the larger coil and the resistance to be measured, 120 elements, the latter circuit having 12 times the battery power, requires 12 times as much resistance in order that the current may have the same effect on the needle as the current from the smaller battery. Hence, if we retain the same value for the respective resistances, we find,

$$\frac{g_1 + W}{12\,(g + \rho)} = K$$

or,

$$W = 12\,(g + \rho)\,K - g_1$$

and when again we neglect g and g_1,

$$W = 12\,\rho\,K.$$

Consequently, if the galvanometer has two coils, one consisting of 100 convolutions and the other of 10,000, and if we place in the battery circuit with the former coil a battery of 10 elements, and in the circuit of the other coil 120 elements, then the resistance of the rheostat may be about $\frac{1}{12 \times 100}$ or $\frac{1}{1200}$ of the resistance which is to be measured. If, for instance, the resistance coils

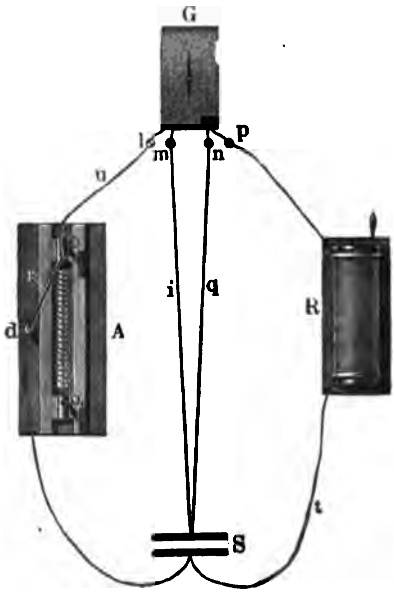


Fig. 138.

(R) contain a total resistance of 10,000 units, then we may, according to the preceding method, measure resistances of 1200 × 10,000 or 12,000,000 units.

If we have two rheostats, then we may (within certain limits of the resistance to be measured) proceed in the following manner:

We take a differential galvanometer G, having equally powerful but opposing coils *l m* and *n p* (fig. 138). The extreme ends *m* and *n* are connected by means of the wires *i q* with one of the

poles of the battery S, the other ends, l and p respectively, with the rheostat R, and the circuit-closing apparatus A. The latter serves to put in or take out at pleasure the wire or resistance which is to be measured (in the drawing represented as a spiral) in the circuit of battery S. For this purpose we connect a wire, k, from the battery pole to the mercury cup d; a movable wire r connects this with another mercury cup o, and the latter, by means of the wire u, is in connection with the binding screw l of the galvanometer.

The current from the battery S now passes through both wires i q to the separated coils of the galvanometer, which are arranged so that the branch currents shall pass around the needle in *opposite directions;* one of these passes through the rheostat R, the other when the wire r, as represented in the drawing, is connected with o through the wires u, r and k.

Now the rheostat is so adjusted that both circuits offer the same resistance, consequently the strength of the current in each is the same, and the needle of the instrument G remains in a state of rest, that is, at 0°.

Now, if we turn the wire r so as to connect it with o_1 instead of o, and place the resistance which we wish to measure between o and o_1, then the part of the current formerly passing directly through k, r and u to the galvanometer must go through k r o_1, and the resistance which is to be measured, to o, thence through u to G; on account of the larger resistance in the left hand circuit the strongest current will flow to the right, and, therefore, the needle is deflected by the latter current. Now, if we insert in the right hand circuit (by turning the rheostat) so much of the rheostat wire that the needle of the instrument again stands at zero, then we evidently have found in the resistance of the added rheostat wire the resistance of the piece of wire between o and o_1 which we wish to measure.

THE METHOD OF COMPENSATION.

This method consists in comparing, by means of a sine-galvanometer, the strengths of current which one and the same battery

produces in two circuits, of which one has a known resistance and the other the resistance which is to be measured.

Suppose a represents the resistance of the battery S (fig. 139) and that of the galvanometer G; between o and o_1 we may insert one after the other the known rheostat resistance R and the resistance A B C = W, which is to be measured. Suppose now, with the rheostat R inserted, that the galvanometer needle gives an angle of deflection α, and with A B C inserted the angle α_1, then the strength of the currents are proportioned to the sine of the angle of deflection; hence, when s and s_1, which are the strengths of current corresponding to the angles of deflection α and α_1, then

$$s : s_1 = \sin. \alpha : \sin. \alpha_1,$$

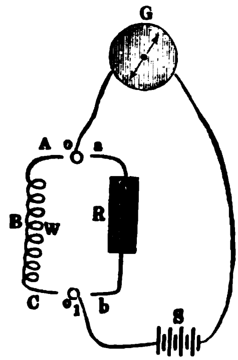


Fig. 139.

According to Ohm's law, however, we have also, when E is the electro-motive force of the battery, and a the resistance of the battery and the galvanometer,

$$s : s_1 = \frac{E}{a + R} : \frac{E}{a + W} = \frac{1}{a + R} : \frac{1}{a + W},$$

hence is

$$\frac{\sin. \alpha}{\sin. \alpha_1} = \frac{a + W}{a + R}$$

consequently,

$$W = (a + R) \frac{\sin. \alpha}{\sin. \alpha_1} - a.$$

The resistance a may be ascertained by a preliminary test; R, α, α_1 are known values. These substituted in the equation determine W.

When great accuracy is not required, we may neglect the resist ance a of the galvanometer and battery; we then get

$$W = R.\frac{\sin. \alpha}{\sin. \alpha_1};$$

as we may take for angles which do not exceed twenty-five degrees, without committing any material error, instead of the sine, the angle itself, hence we obtain, when the angles of deflection α and α_1 do not extend beyond this limit,

$$W = R.\frac{\alpha}{\alpha_1}$$

For instance, if we obtain, by inserting a rheostat resistance of R = 2,000 Siemens units, a deflection of 16°, on inserting the unknown resistance A B C, a deviation of 7°, we have as an approximate value of the resistance:

$$W = 2{,}000 \times \frac{16}{7} = 4{,}571 \text{ Siemens units.}$$

When the resistance to be measured is very great compared with the rheostat resistance R, instead of the above we may use two batteries of an unequal number of elements. For instance, in the first experiment, where we insert the rheostat R, we take n elements, and the second experiment, after having inserted the resistance A B C, we take n_1 elements, then we get, when E represents the electro-motive force, w the resistance of an element and g the resistance of the galvanometer:

$$\sin. \alpha : \sin. \alpha_1 = \frac{n\,E}{n\,w + g + R} : \frac{n_1\,E}{n_1\,w + g + W};$$

or, under the condition that α and α_1 do not exceed 25°, and the battery and galvanometer resistance may be neglected in comparison with R and W,

$$\alpha : \alpha_1 = \frac{n}{R} : \frac{n_1}{W};$$

hence,

$$W = R. \frac{\alpha}{\alpha_1} \times \frac{n_1}{n}.$$

For instance, if $n = 10$, and $n_1 = 120$ elements, then,

$$W = 12 \times R \times \frac{\alpha}{\alpha_1}$$

and on the supposition that R = 2,000 Siemens units, $\alpha = 16°$, $\alpha_1 = 7°$,

$$W = 12 \times 2{,}000 \times \frac{16}{7} = 54{,}857 \text{ Siemens units.}$$

When we change the number of elements in a battery, the

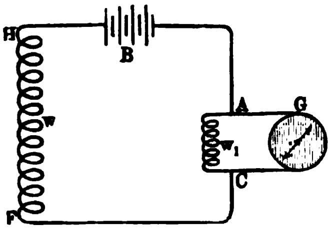


Fig. 140.

electro-motive force does not remain unchanged; although, in general, it cannot be said to be strictly proportional to the number of elements. Now, in order to reduce the sensibility of the galvanometer for a certain battery, we may treat it in a different way.

Let fig. 140 represent the battery, H F = w, the resistance to be measured, G the galvanometer. By inserting the known resistence w_1 between the wires A and C, which lead to the galvanometer, we form a shunt of known resistance, and the current divides itself between the coils A C of the galvanometer G and the inserted branch w_1, so that only a part of the current generated by the battery passes through the galvanometer.

If we indicate the resistance of the galvanometer by G, that of the shunt by w_1, the current passing through the galvanometer

by s, and the current which flows in the undivided wire from B to A by S, then

$$s = S.\frac{w_1}{w_1 + G}$$

Now, if we make $w_1 = \frac{1}{99}$. G, then the current passing through the galvanometer is

$$s = \frac{1}{100}. S.$$

Hence the battery B acts with only $\frac{1}{100}$ of its force on the galvanometer G.

It is true that by inserting the resistance w_1 the strength of the main current is somewhat augmented. When, however, the resistance of the circuit is very considerable, the shunt has but little influence upon it.

MEASUREMENT BY THE WHEATSTONE BRIDGE.

If the differential galvanometer were as perfect practically as it is theoretically, it would enable us to make nearly all electrical measurements with great accuracy; but the difficulty of adjusting the two halves of the coil, so as to have at the same time equal resistances and equal inductive effects, prevents its use where minute accuracy is required, although it is very well suited for making all the ordinary practical tests which are necessary in telegraphy. All the advantages, however, which could theoretically be anticipated from that instrument, may be practically obtained by means of the Wheatstone Bridge, or Balance, as it is sometimes called.

The principle of the differential galvanometer consists in the arrangement of a coil composed of two wires of equal lengths and resistances, so that if currents of equal strength are sent through them in opposite directions the effect on the needle is null. The principle of the Wheatstone Bridge, which has already been referred to on page 206, is that of causing the compensating currents to pass in opposite directions through a coil composed of one wire, by a peculiar arrangement of resistances. This ar-

rangement obviates the difficulties mentioned in the construction of the differential galvanometer, because the movements of the needle are solely dependent upon the alteration in the relative values of the resistances, and in no way upon their inductive effect.

Fig. 141 represents a board on which are placed four copper wires, *Zb*, *Za*, *Ca*, *Cb*, the extremities of which are fixed to brass binding screws. The binding screws Z C are connected respectively with the two poles of a battery, while those marked *a b* are connected with the ends of the wire of a galvanometer. By this arrangement a wire from each pole of the battery proceeds to each end of the galvanometer wire, and if the four wires be of equal length and thickness, and of the same material, perfect

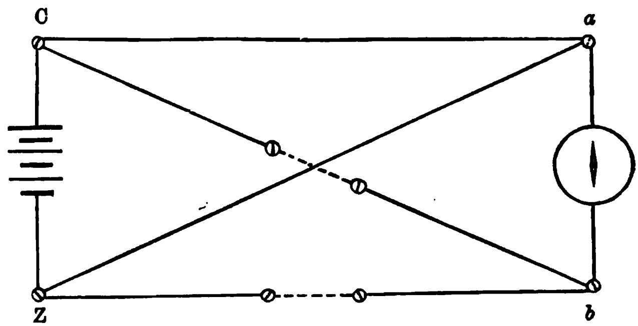


Fig. 141.

equilibrium is established, so that a battery, however powerful, will not produce the least deviation of the needle of the galvanometer from zero. The circuits Z *b a* C Z, and Z *a b* C Z are in this case precisely equal; but as both currents tend to pass in opposite directions through the galvanometer, which is a common part of both circuits, no effect is produced on the needle. Currents are, however, established in Z *b* C Z and Z *a* C Z, which would exist were the galvanometer entirely removed. But if a resistance be interposed in either of the four wires, the equilibrium of the galvanometer will be disturbed. If the resistance be interposed in *Zb* or *Ca*, the current Z *a b* C Z will acquire a preponderance. If it be inserted either in *Za* or *Cb*, the opposite

current, $Zb\ a\ C\ Z$, will become the strongest. If the resistance interposed in the wire be infinite, or what is the same thing, if the wire, which we will suppose to be Cb, be removed, the strength of the current passing through the galvanometer will be that of a partial current $Z\ b\ a$, passing through one of the wires, plus the galvanometer wire; the path of the diverted portion of the current being Za. According to this disposition, the force of the original current $= \dfrac{E}{R + 2r + g}$, and that of the partial current acting on the galvanometer $\dfrac{Er}{R\,(3r + g) + 2r_2 + rg}$; R being the resistance of the battery; r that of a single wire, and g that of the galvanometer.

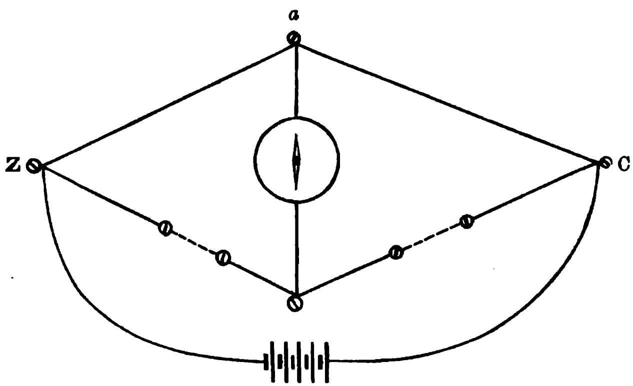


Fig. 142.

The equilibrium having being disturbed by the introduction of a resistance in one of the wires, it may be restored by placing an equal resistance in either of the adjacent wires. For the purpose of interposing the standard resistance or rheostat, and the helix, wire or other resistance to be compared with it, the wires Zb and Cb are interrupted, and provided with binding screws for the reception of the ends of the wires. The equilibrium, when once established, is not in any degree affected by fluctuations in the electro-motive force of the battery.

Fig. 142 represents another arrangement of the wires of the bridge in the form of a lozenge, which is the one generally em-

ployed to describe the balance, although in practice the apparatus seldom bears this form. On comparing it with fig. 141, it will be seen that the connections of the resistances and galvanometer in the two are identical, and that they are, in the second diagram, only put into a more convenient form. The latter diagram is more readily borne in mind, and affords great assistance both in comprehending the principle involved and in arranging the connections for a test. The same reference letters are employed, and the preceding observations apply to it equally.

The principle of the Wheatstone Bridge may, perhaps, be more readily understood, if we illustrate its operation by the variations in the potentials of the electric current upon the various parts of the balance, instead of the quantity of current passing through them, the latter being always proportional to the difference in potential between any two points on the conductor.

If we call the tension at the copper pole of the battery +, and that at the zinc pole —, the tensions in each branch of the bridge, providing the resistances are the same, will fall regularly and gradually from the end which is attached to the copper pole, and will rise regularly and gradually from the end which is attached to the zinc pole, until they both meet in the middle of the wire, where they will be at zero.

The circuit is always divided at some point in the bridge into two branches, and at this point the tensions are equal, while at some other point the two branches are united and the tensions are again equal, whatever may be the lengths of the two intervening circuits. If the resistances are the same in each branch, the tensions will be equal at any two points on the two branches at the same distance from either pole.

In fig. 142 the bridge is composed of four wires of equal length, size and resistance, with a galvanometer connected across at the junctions *a* and *b*, and the two poles of a battery connected respectively with C and Z. The current enters the bridge at C and divides into two equal portions, one half traversing the wire C *b* Z, and the other half traversing the wire C *a* Z. As the tensions at *a* and *b* are both zero, no current will pass be-

tween these two points, and consequently the needle of the galvanometer is not affected.

Under the conditions above described the currents between *a* and C and *b* and C are both +, while those between *b* and Z and *a* and Z are both —. If a resistance be inserted in the wire *b* C, the zero point will change from *b* to a point nearer C, the potential at *b* will become —, or less than zero, and a current will flow across the wire between *a* and *b*, through the galvanometer, proportional to the difference in potential at these points. If a resistance be now inserted between *b* and Z, equal to that be-

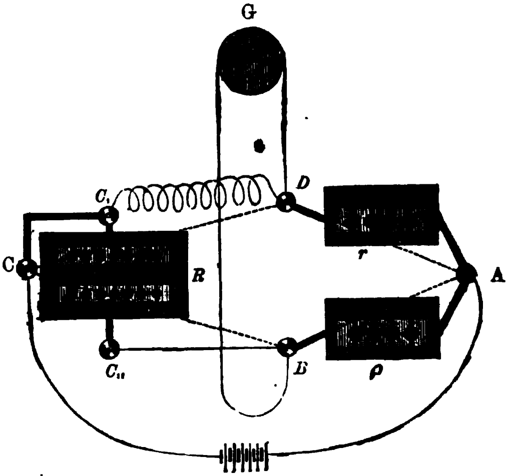


Fig. 143.

tween *b* and C, the zero point of the tensions will return again to *b*, and no current will pass between *a* and *b*.

When the needle stands at zero the following relations always exist between the four wires composing the bridge: If Z*a* is equal to Z*b*, then C*a* is equal to C*b*; or if Z*a* is equal to C*a*, then Z*b* must be equal to C*b*. When Z*a* bears the same proportion to Z*b* that C*a* does to C*b*, no current will pass between *a* and *b*, because the potentials in each branch of the circuit will change in the same proportion and will be equal at the junctions *a* and *b*.

Fig. 143 represents an arrangement of the bridge suitable for the measurement of either large or small resistances.

A, B, C, D are the four terminal divisions of the bridge; r is a rheostat containing three resistance coils of 10, 100 and 1,000 ohms each; ρ is a rheostat exactly similar to the preceding, and these two rheostats are connected on one side with the + pole of the battery. On the other side, r is connected with the galvanometer G and the unknown resistance X, and ρ is connected with the rheostat R at C″, and thence with the — pole of the battery, to which the unknown resistance is also connected through C.′ The galvanometer G has a coil or multiplier containing about 22,000 turns of wire, and offers a resistance of 6,000 ohms.

The resistance in r and ρ being the same, in order to ascertain the resistance of X, it is only necessary to calculate the resistance unplugged in the rheostat R in order to bring the needle of the galvanometer to zero, as the resistance inserted in R is exactly the same as the resistance of X.

It is always necessary to place some resistance in DA and BA when a considerable resistance is inserted between DC and BC, otherwise there would be no appreciable difference in the tensions at D and B, whatever the variations in the resistances of CB and CD might be. The greater the resistance to be measured, the greater should be the resistances inserted in DA and BA.

If the resistance of the wire, helix, cable or other resistance to be measured, which is inserted between C′ and D, is neither greater nor smaller than any of the resistances contained in the rheostat R, which is inserted between C and B, then by unplugging the proper resistance in R the needle will be brought to zero, and the resistance unplugged will be equal to the unknown resistance, for DA : BA : : DC : BC; and as DA is equal to BA, DC and BC must also be equal.

If the resistance to be measured is greater than that contained in the rheostat R, the resistance of ρ must be made less than that of r, and the resistance unplugged in R must be multiplied by the proportion which exists between r and ρ. If, on the contrary, the resistance to be measured is less than the smallest resistance in the rheostat R, ρ is made greater than r, and the

resistance unplugged in R must be divided by the proportion which exists between r and ρ. For example, in measuring a resistance greater than that of the rheostat R, suppose ρ to have a resistance of 200 ohms, r 300 and R 10,000, then

$$\rho : r :: R\ X;\ \text{or, } 200 : 300 :: 10{,}000 : 15{,}000 \text{ ohms.}$$

In measuring a resistance less than that of the rheostat R, suppose it to have a resistance of 25 ohms, r 5 and R 1, then

$$\rho . r :: R : X;\ \text{or } 25 : 5 :: 1 : 0.2 \text{ ohms.}$$

The value of the unknown resistance X may also be determined by the following equation:

Let r represent the resistance inserted in DA, ρ the resistance in BA, R the resistance unplugged in BC, in order to bring the needle to zero, and X the unknown resistance in DC, then

$$\frac{r}{X} = \frac{\rho}{R.}$$

It will be seen, by examining fig. 143, tnat the three sides of the bridge DA, BA and BC are really composed of resistance coils, the intervening wires or metallic rods having no appreciable resistance, and only serving as connectors between the coils. In practice it is quite common to unite r and ρ in one box, having two parallel sets of resistance of 10, 100 and 1,000 ohms. With the Wheatstone Bridge resistance can be measured ranging from .01 of an ohm to 1,000,000 with the same degree of exactness.

METHODS OF MEASURING SMALL RESISTANCES.

The principal piece of apparatus used besides a battery and a galvanometer is a Wheatstone Bridge, of the form usually made by Messrs. Elliott Bros., for purposes of demonstration and research.

Fig. 144 shows the arrangement of its essential parts on a scale of about one ninth. A piece of German silver wire, E F, from 1.5 millimetres to 2 millimetres in diameter and 1 metre long, is stretched upon an oblong board forming the base of the instru-

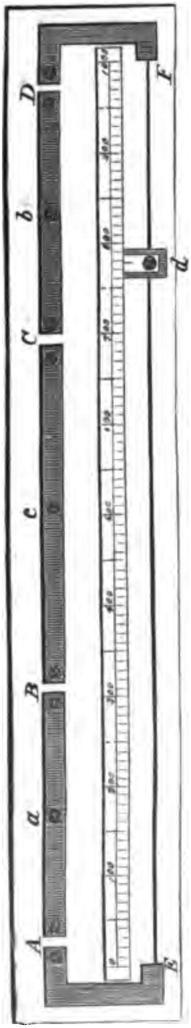


Fig. 144.

ment, parallel to a metre scale divided throughout its whole length into millimetres, and is so placed that its two ends are approximately opposite to the divisions 0 and 1,000 respectively of the scale. The ends are soldered to a broad copper band, which passes round each end of the scale and runs parallel to it on the opposite side from the wire. This band is interrupted by four gaps, A B C and D, at each side of each of which is a binding screw for connecting the conductors whose resistance is to be measured. In the ordinary use of the apparatus the wires from the battery are attached to the screws *a* and *b*, fixed upon the copper strips A B and C D respectively, and the galvanometer wires are connected, one to the screw *c* on the strip B C, and the other to the screw *d* upon a movable block, which slides along the graduated scale and allows contact to be made at any part of the German silver wire, while an index mark shows the distance of the point of contact from each end of the scale. The conductors to be compared are inserted at the two middle gaps, B and C, and if they are of small resistance, the end gaps, A and D are usually closed by thick copper latches, or, if the resistances at B and C are considerable, conductors, whose resistances are known in terms of that of the wire E F, are inserted at A and B; it is easy to see that the effect of these, which may be regarded as non-graduated prolongations of the German silver wire, is to increase the delicacy but to limit the range of the instrument. When the movable contact *d* has been so placed that, on completing the battery circuit, the galvanometer shows no deflec tion, it follows, from the general principle on which the measure-

ment is founded, that resistance a to c : resistance c to b = resistance a to d : resistance d to b. In most cases we may substitute for this, as a fair approximation,

Resistance at B : resistance at C = resistance E to d + resistance at A : resistance d to F + resistance at D, or

$$= \text{scale reading} + \left\{ \begin{array}{c} \text{length of wire equal} \\ \text{in resistance to A} \end{array} \right\} : 1{,}000$$

$$- \text{scale reading} + \left\{ \begin{array}{c} \text{length of wire equal} \\ \text{in resistance to D} \end{array} \right\};$$

but in adopting this last value as representing the ratio of the resistances at B and C, we are exposed to sources of error which become of greater importance in proportion as the resistances to be compared are smaller. These errors are almost entirely avoided in the process now to be described.

The resistance of any wire which is less than that of the whole length of graduated wire, E F, may be found in terms of the latter as follows: Insert the wire to be measured at the gap A, close the gap D by a conductor of insensible resistance, and insert at B and C any two convenient conductors, the ratio of whose resistances (which it is not necessary to know) does not differ from unity more than does that of the resistance to be measured and the resistance of the whole wire E F; then shift the movable contact d until the galvanometer ceases to be deflected and take the reading of the scale. Next put the wire to be measured at D and close the gap A by a conductor without sensible resistance; shift d until the galvanometer is again balanced and take a second reading of the scale; the difference of the two scale readings gives the length of the wire E F whose resistance is equal to that of the wire to be measured.

In the above measurement we assumed the condition D = 0. If m_0 and m'_0 be the scale readings corresponding to this condition, we have

$$\text{A} = (m'_0 - m_0)\, k.$$

in which k indicates the resistance of the unit length (1 millimetre) of the wire E F. But since in practice the resistance D can

never be reduced absolutely to nothing, it is important, when great accuracy is required, that its value should be known: a method is given further on by which any resistance great enough to affect sensibly the reading of the instrument can be measured.

In order that measurements thus made may have a definite meaning, it is necessary that the value of k, or the resistance of the unit length of the wire E F should be known with reference to some recognized standard; and when the resistance of the whole wire E F is a comparatively small fraction of a unit, some special method is needed for measuring k.

Two methods may be employed for this purpose, the one which is, on the whole, the most convenient, being the following: A wire whose resistance, R, is only a little less than that of the whole wire E F, is measured in terms of the latter by the process given above: let p be the number of millimetres between the two readings of the positions of the sliding contact, then

$$k\,p = \mathrm{R} \ldots\ldots\ldots (\mathrm{I})$$

Next a standard (unit) coil of resistance, S, is combined in multiple arc with the wire already measured, and the measurement is repeated; this gives, if q be the number of millimetres between the two readings in this case:

$$k\,q = \frac{\mathrm{R\,S}}{\mathrm{R}+\mathrm{S}} \ldots\ldots\ldots (\mathrm{II})$$

Whence we get, as the value of the coefficient required.

$$k = \mathrm{S}\,\frac{p-q}{p\,q}.$$

Another method is to insert a standard coil at one of the gap ends (say at A) and at the other (D) a wire whose resistance, R, falls short of that of the standard by not quite the whole resistance of E F, and to shift the movable contact until the galvanometer is balanced; then to interchange the standard and the resistance, R, and shift the contact again till the balance is restored: let d be the difference (in millimetres) between the two readings

of the scale in this experiment. Next, take a second wire whose resistance, R_2, falls short of that of R_1 by nearly the whole resistance of E F, and proceed with this and the first wire in the same way as with the first wire and the standard, and let d be the difference between the two readings of the scale in this case. Proceed in this manner with wires of smaller and smaller resistance until one is arrived at of smaller resistance than the wire E F. Let the resistance of this wire be R_n: by inserting it at one of the end gaps and an insensible resistance at the other, and afterwards interchanging, we find, by taking the difference, d_n, of the scale readings in the two positions required to balance the galvanometer, the number of millimetres of the graduated wire whose resistance is equal to R_n. By a set of such experiments we obtain:

$$\begin{aligned} d\,k &= S - R_1, \\ d_1 k &= R_1 - R_2, \\ &\vdots \\ d_{n-1}k &= R_{n-1} - R_n, \\ d_n k &= R_n; \end{aligned}$$

or

$$k = S \frac{1}{d + d_1 + \dots + d_{n-1} + d_n}.$$

It has been assumed in the foregoing that the coefficient k, or the resistance of 1mm. of the graduated wire E F, is constant from end to end. This is never strictly the case, and hence it is desirable to measure not only the mean value of this coefficient for the whole wire, but also its value for the different parts, or else to assure ourselves that the variations are too small to be of importance. This examination of the wire is very readily made by the arrangement represented in fig. 145, which shows a second graduated wire E′ F′ connected with a bridge of the form already described. So far as the same reference letters occur in this figure and in fig. 144, they mark identical parts: the battery is connected (through a make-and-break key not shown in the figure) with the binding screws a and b, and terminals of the galvanometer are connected with two movable contact makers, one of them m on the principal wire E F, and the other n on the wire E′ F′.

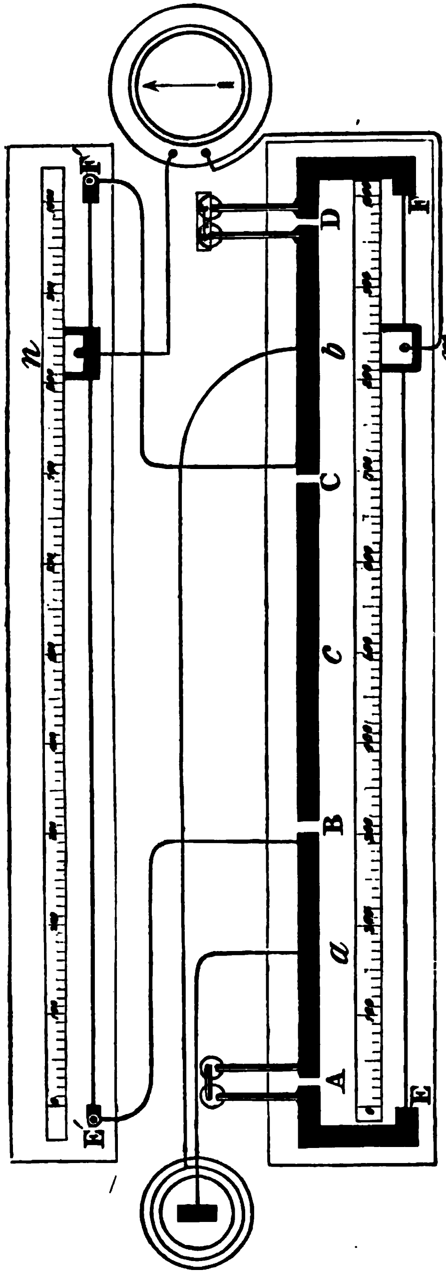


Fig 145.

For convenience of reference this will be hereafter called the "compensating wire" or "compensator"—the ends of which are connected with the outer binding screws of the gaps B C. The end gaps A and B are closed, one by a short and very thick piece of copper wire of almost insensible resistance, and the other by a short piece of German silver wire of resistance equal to that of whatever length of the graduated wire it is desired to test at once. This piece of wire serves the purpose of a gauge, with which each part of the wire E F is compared in succession. The gauge being (say) at the right hand gap D (as in the diagram) the sliding contact *m* is placed at or very near to the right hand end of E F, and the slider *n* is moved on the compensating wire so as to balance the galvanometer. The gauge and the thick copper connector are next interchanged, and the balance is restored by moving the slider *m*. As already pointed out, the length of E F over which the slider is moved, is that of which the resistance is equal to the difference between the resistances of the gauge and the thick connector. The gauge and connector are now put back into their first positions, and the slider *n* is shifted until the galvanometer is again balanced; then they are interchanged once more and the balance obtained by shifting the slider upon E F. This process of successively interchanging the gauge and connector, and adjusting the galvanometer to zero, by moving alternately the sliders *m* and *n*, is continued until the former has been brought step by step to the further extremity of the wire E F. It will be seen that each shift of the sliding contact *m* is over a portion of the wire E F, whose resistance is equal to the constant difference between the resistances of the gauge and connector, and therefore that the graduated wire is divided into parts of equal resistance, in a manner similar to that in which a thermometer tube is "callibrated," or divided into portions of equal capacity, by marking on it the lengths successively occupied by a small quantity of mercury which is pushed along it.

The shift of the slider *n* also takes place over portions of the wire E′ F′ which have all an equal resistance, but this bears the same ratio to the resistance represented by the shifts of the

slider m that the resistance of the branch a B E′ F′ C b bears to the resistance of the branch a A E F D b. To prove this, let the sliders be so placed that the galvanometer is in equilibrium when the gauge is at the gap D, and the gap A is closed by the thick connector: let the resistance of the gauge be denoted by G, that of the connector by C, the resistances of the wires E F and E′ F′ by L and L′ respectively, those of the permanent connections between a and E and between a and E′ by e and e', the permanent resistances between b and F and between b and F′ by f and f', and lastly the resistances of E m and E′ n by r and r'. We then have the equation—

$$\frac{\mathrm{C}+e+r}{\mathrm{G}+f+\mathrm{L}-r}=\frac{e'+r'}{f'+\mathrm{L}'-r'} \quad \cdots\cdot \quad (1)$$

Then, by interchanging the gauge and connector and balancing the galvanometer again by moving the slider n nearer to F′, while the slider m remains where it was, we get the equation

$$\frac{\mathrm{G}+e+r}{\mathrm{C}+f+\mathrm{L}-r}=\frac{e'+r'_1}{f'+\mathrm{L}'-r'_1} \quad \cdots\cdot \quad (2)$$

where r'_1 is the resistance between E′ and the new position of n, and therefore $r'_1 - r'$ is the resistance of that portion of the compensating wire over which the slider has been moved. By adding unity to each side of each of the equations (1) and (2), inverting the two new expressions thus obtained, and subtracting one from the other, we get

$$\frac{r'-r'}{e'+f+\mathrm{L}}=\frac{\mathrm{G}-\mathrm{C}}{\mathrm{G}+\mathrm{C}+e+f+\mathrm{L}}$$

or

$$r_1'-r=(\mathrm{G}-\mathrm{C})\,\frac{e'+f'+\mathrm{L}'}{\mathrm{G}+\mathrm{C}+e+f+\mathrm{L}} \quad \cdots \quad (3)$$

which shows that, with the same apparatus, at each shift of the movable contact along the compensating wire, it passes over a constant resistance of the magnitude stated above.

The value of the multiplier of G — C in equation (3) is easily found experimentally; for, since the resistance passed over at

each shift of the slider on the principal wire E F is equal to the difference G — C, denoting this resistance by $r_1 - r$, we obtain

$$\frac{e' + f' + L'}{G + C + e + f + L} = \frac{r'_1 - r}{r_1 - r} = M.$$

By help of this value, which for shortness may be denoted by M, exceedingly small resistances, such as that of the short copper connector mentioned above, are readily measured when they are connected so as to form part of the principal circuit. For this purpose it is sometimes needful (in order that every measurement may come within the range of the instrument) to transfer the battery wires from the binding screws *a* and *b* to E′ and F′; when that is done, the factor M must be determined in this state of the apparatus, since the resistances e' and f' now belong to the principal branch of the circuit instead of to the compensator branch. The galvanometer wire is now disconnected from the slider *m* and applied to one end of the connector (or other conductor whose resistance is to be measured) and the balance is got by means of the slider *n*; the galvanometer wire is next applied to the other end of the connector, and the balance is again got by the slider. Then if Q be the resistance over which the slider is moved, the resistance of the connector is given by

$$C = \frac{Q}{M}$$

As an example of the resistances which are easily measurable in this manner, it may be mentioned that in two experiments the resistance of a thick and short piece of copper wire has been found to be equal to that of 0.6 millimetre of the German silver wire E F, or to be about 0.0008 of a B. A. unit.

When the graduated wire of the bridge has been divided as above described into sections of equal resistance, it is easy to make a table showing what fraction the resistance of any given part of it is of the total resistance. For the purpose of avoiding errors due to the resistance of connections in determinations of specific resistance, a simple and accurate process is, to connect

the wire to be used for the determination in the place of the German silver wire E F of a bridge of the form shown in figure 144, and to proceed precisely in the manner already indicated for the measurement of the resistance of the unit length of the bridge wire. The result is in this case wholly independent of any resistance outside the extreme positions of the sliding contact maker, and since this is only used for finding a point which gives *no current* through the galvanometer, the result is also unaffected by any moderate variation of resistance at the movable contact itself.

It will be seen that the accuracy of the above methods of measurement depend essentially on the possibility of connecting the conductors inserted at the two gaps A and D with the rest of the apparatus in such a way that they can be taken out and put back again, time after time, without causing any perceptible change in the resistance of the connections. This is accomplished by the use of well amalgamated copper rods, resting by their flat ends on an amalgamated plate of copper, forming the bottom of a mercury cup.

CHAPTER XX.

THE LAWS OF ELECTRO-MAGNETISM.

In order to attain the best result in the construction of electro-magnets, to be used under given conditions or for particular purposes, it is necessary to proceed in accordance with certain laws which govern the action of a coil or helix upon the iron cores enclosed within it. The form in which an electro-magnet is usually constructed has already been described and illustrated (page 102). The general law which governs the magnetizing action of a helix is this: The magnetizing effect of a current flowing through a conductor coiled into a helix or spiral is directly proportional to the strength of the current and to the number of turns in the helix. If we denote the strength of the current traversing the coiled wire by S, the number of convolutions in the helix by n, and the magnetizing power of the helix by p, then

$$p = n\,S.$$

According to the researches of Lenz and Jacobi, the breadth of the helix is without influence on the magnetic effect produced in the iron core, provided the ends of the core project beyond the helix. On the other hand, these physicists found that the magnetism produced is proportional to the strength of the current S and the number of convolutions n, so that when we indicate by c a constant quantity, the simple relation is

$$m = c\,n\,S = c\,p.$$

It has, however, been shown by Müller that this formula is only applicable to weak currents and comparatively heavy iron cores. For stronger currents and cores of smaller diameter, he found the relation to be as follows:

$$p = a\,d^{\frac{3}{2}}\ \text{tang.}\ \frac{m}{b\,d^2},$$

in which d indicates the diameter of the iron core, while a and b are constant multipliers, which vary with the length and number of turns. It follows, therefore, from this equation, that there is for each iron core a maximum of magnetism which cannot be exceeded. If, then, we give to p a value infinitely great, we obtain

$$\text{tang.}\,\frac{m}{b\,d^2} = \infty$$

from which it follows that

$$\frac{m}{b\,d^2} = \frac{\pi}{2}, \text{ and}$$

$$m = \frac{\pi}{2}\,b\,d^2$$

As both b and d have a definite value for the same iron core, it follows that m has always a finite value, which is at the same time the maximum of magnetism which the core is capable of receiving. Hence this maximum is proportional to the square of the diameter, or, in other words, to the sectional area of the core.

The sustaining power of an electro-magnet, or the force with which it acts upon its armature, differs materially from the free magnetism which is developed in its core under the influence of a magnetizing helix. According to Dub's experiments, the sustaining power depends upon the size and form of the armature, and increases generally with the dimensions of the latter. He further discovered that with a given strength of current and an armature of given length, a core of smaller diameter often has more sustaining power than one of larger diameter. It is apparent that, owing to the reaction of the armature upon the electro-magnet, the maximum of magnetization is sooner reached than if there were no armature in contact with the core. Dub also found that the best results were obtained by making the poles of the magnet of the same area as the section of the core, and with a perfectly plane surface; and that no advantage resulted from the enlargement of the surface of the poles. The temperature of the iron core affects to some extent the development of

magnetism therein. With a given strength of current, the higher the temperature the less will be the amount of magnetism developed.

CONSTRUCTION OF MAGNETIZING HELICES FOR ELECTRO-MAGNETS.

The magnetism which a magnetizing spiral produces in an electro magnet is, as we have already seen, proportional to the strength of current and to the number of convolutions, provided the distance between the wire and the iron core does not exceed a certain limit.

In the case of the electro-magnets used in telegraphy, this limit amounts to about half an inch, and when the distance between the core and wire exceeds this limit, the proportional effect of the current upon the iron core rapidly decreases; consequently, the volume of the coil or helix which surrounds an electro-magnet is limited, and when we wish to increase the number of convolutions, the only resource is to reduce the sectional area of the conducting wire.

This being the case, it is not difficult to determine under what conditions a magnetizing helix will produce the greatest magnetic force, provided the strength of the current and the resistance are known.

Let us suppose, in the first place, that the wire makes but a single convolution around the iron core, but that it occupies the entire space intended for the coil. Let the resistance of such a wire be indicated by u. If we now divide it in such a manner that instead of one convolution it makes two, then its sectional area is only half as much but its length is double what it previously was; the resistance of the wire is therefore four times as great as at first, viz., $4u$. In the same way, when the original wire is made into n convolutions instead of two, then the total resistance r of the coil is

$$r = n^2 u$$

Now, if E denotes the electro-motive force of the battery, W the resistance of the battery and the wire, and therefore the whole

resistance outside the coil, we find that the strength of current S, according to Ohm's law, is

$$S = \frac{E}{W + n^2 u};$$

consequently, the magnetic force is

$$M = n\,S = \frac{n\,E}{W + n^2 u}$$

By varying n the magnetic force M of the electro-magnet also varies, and M attains its greatest value when the denominator is the smallest; the latter, for theoretical reasons, is the case when, in the preceding equation,

$$W = n^2 u \ldots\ldots\ldots\ldots (1)$$

or

$$W = r$$

The magnetizing coils of an electro-magnet therefore act most powerfully when their resistance (r) is equal to the total resistance (W) of the circuit outside of the coils.

If we indicate by l, q, s, respectively, the length, sectional area and specific resistance of the wire which surrounds the iron core, then the resistance r of the coil is,

$$r = \frac{l\,s}{q}$$

Hence the action of the coil is a maximum when

$$W = \frac{l\,s}{q}.$$

As only copper wire, whose specific resistance = 1, is employed for the wire coils, we find that for the maximum of magnetic intensity

$$W = \frac{l}{q} \ldots\ldots\ldots\ldots (2)$$

If we take into consideration the fact that the diameter of the coil should not exceed a certain limit, when its magnetizing power is not otherwise restricted, equation (2) gives these conclusions:

1. When the resistance W outside the coil is very large, the the proportion $\frac{l}{q}$ should also be large; the coil should then be made of a wire of great length and small sectional area, or very long and fine wire.

2. When the resistance W outside the coil is small, then the proportion $\frac{l}{q}$ ought to be small also; in this case a short and thick wire should be used.

The former applies more directly to coils of electro-magnets used on long telegraph lines or in circuits where the battery has a great resistance. The latter applies in cases where the electro-magnets are operated by a local battery of small resistance.

CHAPTER XXI.

THE DETERMINATION OF VOLTAIC CONSTANTS.

THE manner in which the strength of a galvanic current is measured has already been explained in a preceding chapter. The adaptability of a galvanic element to any special purpose does not, however, always depend solely upon the strength of current indicated by the galvanometer. For this reason a knowledge of the strength of current alone, is not in all cases sufficient to determine what the effect of a battery will be in practice. This may be illustrated by an example. Suppose the electro-motive force of a certain element be 480, its internal resistance 20, and the resistance of a galvanometer included in the circuit 40, then the strength of current will be

$$\frac{480}{20 + 40} = 8.$$

With an element having an electro-motive force of 400 and an internal resistance of 10, the insertion of the same galvanometer will produce the same strength of current,

$$\frac{400}{10 + 40} = 8.$$

Now, although both elements produce the same deflection of the galvanometer needle, it would not be correct on that account to suppose that they would produce the same effect in all cases, or that they may be substituted for each other.

When we include another apparatus, for instance, an electro-magnet, whose resistance is only 10, in the circuit of both elements instead of the galvanometer, the strength of current given by the first element is $\frac{480}{20 + 10} = 16$, while that of the second is $\frac{480}{10 + 10} = 24$, so that in this particular case it is preferable to make use of the second element instead of the first one.

For the same reason, an element may appear to be constant when in circuit with a galvanometer, in case its electro-motive force and its resistance should happen to vary in a corresponding proportion, while in actual use it may prove a very inconstant one, and *vice versa*. In order, therefore, to ascertain beforehand whether or not a given galvanic combination is adapted to any particular use, we should determine what are called its constants—that is to say, the several factors which influence the strength of current; and also how, and to what extent, these vary while in action in the special case under consideration. These so-called constants are the internal resistance, the electromotive force, and the polarization which are contained in the element.

MEASUREMENT OF THE INTERNAL RESISTANCE OF A BATTERY.

The resistance of a galvanic element or battery may be determined by various methods.

I. One of the simplest of these is that of observing the strength of current; first, when there is no external resistance in circuit, and again after inserting a known resistance, l. If, as heretofore, we indicate the two strengths of current measured by an inserted tangent galvanometer by S and S_1, the electromotive force by E, the resistance of the element and the galvanometer taken together by x, and the resistance of the inserted wire by l, then, according to Ohm's law,

$$S = \frac{E}{x}$$

$$S_1 = \frac{E}{x + l}$$

and, by combining the two equations, we get for the resistance of the element and the galvanometer together,

$$x = \frac{S_1}{S - S_1} l \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Now, when α and α_1 are the angles of deflection, and M the

magnetic power of the needle, S = M tang. α, and S_1 = M tang. α, and we have

$$x = \frac{\text{tang. } \alpha_1}{\text{tang. } \alpha - \text{tang. } \alpha_1} l$$

This includes the resistance of the galvanometer and the required connecting wires; the latter resistances, however, are very easily determined by the methods previously given, and being thus found, if we deduct them from the value obtained for x, the remainder will be the resistance of the element alone.

The following will serve as a practical example of this method: A Gaugain tangent galvanometer (fig. 91, page 138,) was connected in circuit with a set of resistance coils (fig. 117, page 181,) and a cell of gravity battery (fig. 35, page 57). When the resistance coils were all plugged, the deflection of the galvanometer was 65°, while by the insertion of 1 ohm resistance in the rheostat the deflection was reduced to 57½°. We have seen (page 137) that the strength of current is in proportion to the tangent of the angle of deflection produced. By referring to a table of tangents we find that the tangent of 65° is 2.45, and that of 57½° is 1.57. The resistance of the galvanometer coil was 0.78° ohms. Therefore, we have

$$\begin{aligned} S &= \text{tang. } 65^\circ = 2.45 \\ S_1 &= \text{tang. } 57\tfrac{1}{2}^\circ = 1.57 \\ l &= 1 \text{ (ohm)} \end{aligned}$$

Then, according to equation (1), the value of the unknown resistance of the battery is

$$x = \frac{1.57}{2.45 - 1.57} = 2.73$$

From this, however, we must deduct the resistance of the galvanometer, 0.78 ohms, which gives us as the resistance of the battery itself, 1.95 ohms.

II. If we wish to bring the resistance of the galvanometer directly into our calculation, let us express

By x, the resistance of the element.

" S, the measured strength of current for any unit of resistance = w.

By S_1, a second strength of current for any smaller resistance $= w_1$

" t, the resistance of the galvanometer.

" E, the electro-motive force, then we shall have

$$S = \frac{E}{x + t + w}$$

$$S_1 = \frac{E}{x + t + w_1}$$

whence it follows that

$$\frac{S}{S_1} = \frac{x + t + w_1}{x + t + w}$$

and

$$x + t = \frac{w\,S - w_1 S_1}{S_1 - S}$$

whence

$$x = \frac{w\,S - w_1\,S_1}{S_1 - S} - t.$$

In case the measurements are made with a tangent galvanometer, we shall obtain, according to the preceding example,

$$x = \frac{w \text{ tang. } \alpha - w_1 \text{ tang. } \alpha_1}{\text{tang. } \alpha_1 - \text{tang. } \alpha} - t \ldots\ldots\ldots\ldots (2)$$

The same cell was measured by this method with the following results:

$w = 3$ (ohms)
$w_1 = 1$ (ohm)
tang. $\alpha = 1.018$
tang. $\alpha_1 = 1.57$
$t = 0.78$ (ohms)

According to equation (2) the value of x was found to be

$$x = \frac{(3 \times 1.018) - (1 \times 1.57)}{1.57 - 1.018} - 0.78 = 1.90 \text{ ohms.}$$

With the sine galvanometer (figs. 93 and 94) the method to be followed is precisely the same. The formula in this case would be

$$x = \frac{w \sin \alpha - w_1 \sin \alpha_1}{\sin \alpha_1 - \sin \alpha} - t \ldots\ldots\ldots\ldots (3)$$

The resistance t of the galvanometer is usually small; when only a single turn of the ordinary tangent galvanometer (fig. 90) is used, it is but a small fraction of a unit: it may, therefore, be neglected entirely when an instrument of this kind is employed.

III. Mance's method of measurement consists simply in substituting the battery of which the resistance is to be measured for the resistance in one branch of the Wheatstone bridge (page 241), and adjusting the resistances until the needle of the galvanometer is deflected from zero, and maintains its deflection constantly when contact at the cross-wire of the bridge is made and broken. In the following illustration (fig. 146) A, B, E, and R are the four sides of a Wheatstone bridge, K a contact key, G the galvanometer, E being the battery whose resistance

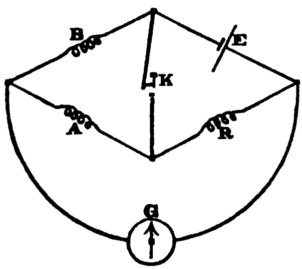


Fig. 146.

is to be measured. Now, when $AE = BR$ the resistance becomes determined; or, supposing A and B to be two equal resistances, E and R will be equal. Having placed the battery in one of the branches of the bridge, we make and break contact at K, and if there be no change in the deflection, we know that $AE = BR$, and $E = \frac{BR}{A}$. Practically the result is independent of the galvanometer resistance. It is convenient to give to the constant branches of the bridge a ratio by which the unplugged resistance may be multiplied.

The method admits very easily of experimental proof; for if we make the resistance R great, we shall have a larger deflection when K is open than when pressed down; but if R is small, then

when K is pressed down we shall have the larger deflection. Evidently there must be some value for R at which the closing or opening of K does not affect the deflection; and if A and B are equal, this value will be the resistance of E.

Applying this method to the measurement of the cell above mentioned, the resistances A and B were made equal to 1000 and 10 ohms respectively. It was then found that 195 ohms would balance the needle; therefore,

$$1000 : 10 :: 195 : 1.95$$

The resistance of the battery was, therefore, 1.95 ohms, or sensibly the same as before.

IV. Another method for determining the resistance of an element may be recommended when a tangent or sine galvanometer is not available and we have only a multiplier, G, at our command, the resistance of which is known.

The multiplier with a rheostat is connected in circuit, and sufficient resistance unplugged to produce a convenient deflection α. A shunt having a known resistance S (which may be about the same, or greater than that of the coils of the multiplier), is then connected across from one pole of the battery to the other. This will, of course, diminish the deflection of the needle by diverting part of the current from the multiplier. Now decrease the resistance of the rheostat R until the original deflection α is reproduced, and let r indicate this new resistance, then the resistance x of the battery will be

$$x = S\frac{R - r}{r + G}$$

Thus a measurement of the above cell, taken on a different occasion, gave

$$\begin{aligned} R &= 10 \text{ ohms.} \\ S &= 5 \quad " \\ r &= 7 \quad " \\ G &= 1.57 \quad " \end{aligned}$$

consequently, $$x = 5 \times \frac{10 - 7}{7 + 1.57} = 1.75.$$

This is known as Sir William Thomson's method, and is

regarded as one of the most generally useful ones yet made available.

V. The internal resistance of a battery may also be found by means of a differential galvanometer having a thick wire coil, or by shunting the coils of a thin wire differential galvanometer. This method requires a rheostat adjustable to fractions of a unit, if a small number of cells are to be measured at a time.

Fig. 147.

With the differential galvanometer of the Western Union Telegraph Company (fig. 147) the process is as follows:

Connect the positive pole of the battery with binding screw C, and the negative with binding screw 3, inserting a plug at A, and also in the orifice marked $\frac{1}{100}$ on the left hand side of the galvanometer. When the key is depressed, only $\frac{1}{100}$ of the battery current will flow through one half of the galvanometer

coil, $\frac{99}{100}$ passing through the shunt. The deflection of the needle must then be noted. Now connect the positive pole of the battery with binding screw 4, and the negative pole with one end of the rheostat, the other end of which attach to the binding screw 3. Insert plugs at the $\frac{1}{100}$ shunts on each side, and also at A and B. The portion of the current which flows through the galvanometer now passes through both halves of the coil, and the deflection of the needle is consequently increased. Now unplug the resistance coil until the deflection of the needle is the same as it was when the current passed only through one half of the galvanometer coil, and the resistances unplugged will be equal to the resistance of the battery.

The Gaugain differential galvanometer is admirably adapted to measuring the internal resistance of batteries by this method. As thick wires are used, no shunting is necessary.

It is obvious that the resistance of any element depends upon the nature of the liquids, the surface of the immersed metals, the distance between these metals, the character of the porous cells, etc.; it consequently varies accordingly, and thus, when the combinations are the same, the resistance often proves to be quite different.

The measurement of the resistance of a battery is subject to some uncertainty, since the resistance is subject to considerable variation even while the measurement is being made. For accurate determinations it is, therefore, better to take the mean of a number of observations.

Of the galvanic elements in common use the resistance of the Grove battery is least, being usually less than half an ohm for a pint cell. The Daniell is usually from 3 to 5 ohms, and the gravity from 2 to 4 ohms—the two latter depending not only upon the size of the plates and their distance apart, but also upon the degree of saturation of the sulphate of zinc solution.

MEASUREMENT OF ELECTRO-MOTIVE FORCE.

In order to determine the electro-motive force of a given voltaic combination, it is necessary to adopt some definite standard

of measurement. For this purpose a certain strength of current (S) is appropriate. The unit strength of current formerly employed was calculated from the chemical unit, which was explained on page 162, and which, according to Ohm's law, is proportional to the electro-motive force of the element.

This is $$S = \frac{E}{W}.$$

where W represents the total resistance of the element. When in any case W is made to equal 1,

then $$E = S.$$

That is to say, the electro-motive force of an element is equal to the strength of current which it would give when its resistance equals 1. S, or the strength of current, however, indicates the number of cubic centimetres of inflammable gas which the current produces in a minute; the electro-motive force (that is, the number which may be derived from the above expression $E = S\ W$), consequently, indicates the quantity of inflammable gas (in cubic centimetres) which the current produces in one minute when the resistance of the element is equal to 1.

When, for instance, it was said that the electro-motive force of a Daniell element was equal to 470, it was meant that the element would produce 470 cubic centimetres of inflammable gas in one minute when the sum of all the resistances in circuit was equal to 1.

Another measure of electro-motive force was the unit selected by Regnault, which was the electro-motive force of a thermo-electric copper-bismuth element, whose opposite ends are constantly kept at the temperature of 0° and 100° C., respectively.

Regnault's process for determining the electro-motive force of a galvanic element is founded on the principle of opposing a thermo-electric counter-current from so many copper-bismuth elements to the element tested that the currents balance each other. The electro-motive force of the element which is examined is then expressed by the number of thermo-electric elements which are required to produce this result. When the

electro-motive force of a Grove element, for instance, is found to be equal to 310 according to Regnault, then it is meant that a single Grove element has the same electro-motive force as 310 thermo-electric copper bismuth pairs whose opposite ends are at the temperatures of 0° and 100°.

The unit now most generally adopted is that of the British Association, and is termed the volt. The volt is a little less than the electro-motive force of a Daniell element, the latter being equal to 1.079 volts. For ordinary purposes where great accuracy is not required, it is usual to consider the Daniell element as roughly equal to one volt.

The electro-motive force of a galvanic element, like its resistance, may be determined in several ways. It is generally most convenient to make use of the Daniell battery as a standard, as its electro-motive force is probably more uniform than that of any other, and its electro-motive force being known, the results may readily be reduced to volts by multiplying by 1.079. There are two general principles by which the electro-motive force of a battery may be found. One of these is by the application of Ohm's law to a battery in action, where the resistances are known, and the other by allowing the battery to remain inactive, and measuring the potential, in which cases the potential is the same as the electro-motive force, and the resistances in circuit need not be known. The first five of the following methods belong to the former system, and Poggendorff's method is a combination of both.

To compare the electro-motive forces of two batteries:

I. Let their forces be E and E′; join them up successively in circuit with the same galvanometer, and, by varying their resistance, cause them both to give the same deflection; their forces will then be in direct proportion to the total resistances in circuit in each case, or

$$E' = E \times \frac{R'}{R},$$

where R represents the resistance with E (including that of battery, galvanometer, and the variable resistance), and R′ with E.′

II. If the external resistances be made very large indeed in comparison with that of the cells themselves, their internal resistance may often in practice be neglected, and only those of the galvanometer and resistance coil taken into account.

III. When the electro-motive forces differ greatly, it is often necessary to employ a shunt to diminish the deflection of the galvanometer and bring it within range with the more powerful battery. Calling their resistances g and s, their joint resistance will be

$$\frac{g \times s}{g + s}.$$

which must be employed in calculating the total resistance of R; the respective electro-motive forces are then

$$E' = E \times \frac{R \times \frac{g + s}{s}}{R' + g}$$

IV. Where shunts are used in obtaining both the deflections, the formula becomes

$$E' = E \times \frac{R \times \frac{g + s}{s}}{R' \times \frac{g + s'}{s'}}$$

In all these cases $\frac{g + s}{s}$ represents the multiplying power of the shunt (page 147).

V. When a Thomson's reflecting galvanometer is employed (or any other in which the deflections have a known value), it becomes unnecessary to reproduce the same deflection. Calling the deflections d and d' we have

$$E' = E \times \frac{R \times d}{R \times d'}$$

VI. Where a number of cells are joined up in a circuit with, but in opposition to a number of other cells with a galvanome-

ter inserted, and the numbers adjusted so that no current passes, we have an obvious measure of their electro-motive force.

VII. In Poggendorff's method (fig. 148) the more powerful battery, E′, is joined up in circuit with a resistance coil R,

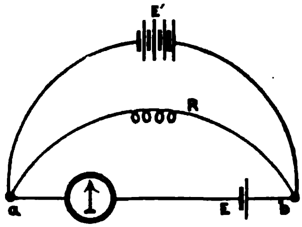


Fig. 148.

and the other battery, E, and a galvanometer are connected to the same coil, so that both batteries send a current through R in the same direction; by increasing the resistance of R it is easy either to make the current of E′ overpower that of E, or to obtain such an equilibrium that E′ shall remain inactive, and no current pass through the galvanometer in either direction. When this is effected we have the following ratio: as the total resist-

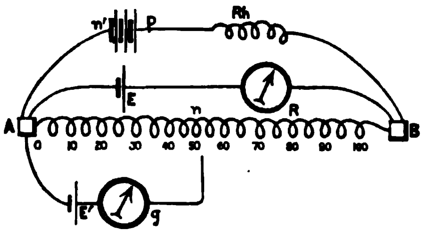


Fig. 149.

ance of r' and R is to the resistance of R, so is the electro-motive force of E′ to that of E

$$E = E' \times \frac{R}{r' + R}$$

VIII. It has been objected to the preceding system, that, since one of the batteries is active and the other not, we do not obtain a true comparison of the forces. Although attaching little importance to this objection, it may be stated that Mr. Clark has employed an instrument depending on similar princi-

ples, to which this consideration does not apply. In fig. 149 R is a coil of platinum wire of 100 turns, wound on an ebonite cylinder, which revolves on its axis like a Wheatstone's rheostat; the ends of the coil are connected to the axles, which work in the blocks A and B; *p n* is a battery of several cells, also connected to the blocks A and B, which sends a continuous current through R. A rheostat, R*h*, is also inserted, by which the total resistance of the circuit can be varied. E is a standard element (or a thermo-electric pile), also connected to the blocks A and B with an intervening galvanometer, which, by a proper adjustment of the rheostat, is just balanced by the battery *p n* in the manner before described, so that no current passes. Thus far the arrangement is similar to that of Poggendorff, except that E is used as the standard of comparison instead of *p n*. E′ is the cell whose potential or electro-motive force we desire to measure, and this is connected with the block A, and galvanometer *g*, and a movable wire *n*, which can be applied to any part of the wire R.

Assuming the standard battery E to be exactly balanced by *p n*, and to have a potential of 100, and calling the potential at A = 0, we have between A and B every potential from 0 to 100; and by applying the wire *n* successively to different parts of the wire R we soon find a point where the potential of E is balanced, no current passing through *g*. A scale of equal parts measured along R gives the potential of the cell E′ by simple inspection.

By the use of a Thomson's galvanometer, and by fixing a divided scale on the revolving cylinder, it is easy to measure potentials accurately to the ten thousandth or hundred thousandth part of a Daniells cell. When the battery E′ which we wish to measure is more powerful than the standard battery E, their positions are reversed, and E is connected to the galvanometer *g* and wire *n*. When this is the case, employing a scale of 100 parts and calling *n* the number of divisions, we have

$$E' = E \times \frac{100}{n}$$

IX. The two elements or batteries to be compared are used in succession to charge a given condenser. Their electro-motive forces are in direct proportion to the charges communicated by them to the condenser. When batteries of very different values are to be compared, a shunt must be used in reading the throw due to the charge current of the larger one. The maximum current of a battery of given surface of plates is obtained when the resistance of the battery is equal to that of the circuit exterior to it.

If we have N elements, the resistance of each being r ohms, and the external resistance of the circuit R ohms, we must arrange the battery in n rows of each $\frac{N}{n}$ elements in series, and these rows we must then connect up parallel with each other. The number of rows will be

$$n = \sqrt{\frac{N\,r}{R}}$$

The resistance of each row being

$$\frac{N}{n}\,r = n\,R \ldots \text{ohms.}$$

For measuring electro-motive forces with Siemens' Universal Galvanometer (an instrument which will be hereafter more fully described) Professor E. du Bois-Reymond's modification of Poggendorff's compensation method is employed.

The upper diagram of figure 150 shows the connections to be made with the instrument. The needle i is to be brought to the zero point of the small scale by turning the galvanometer G round its vertical axis. The pointer or vernier Z, is to be brought by means of the handle to the zero point of the large scale on the slate disc. The hole between III and IV to be left unplugged. Plugs to be inserted in 1, 10 and 100. The two poles of the battery E_0 (which must be greater than E_1 and E_2) are to be connected with the terminals II and III. The poles of the battery which is to be compared to E_0 are to be connected to terminals I and IV in such a manner that the similar poles of the two batteries are joined to terminals I and III and to II and IV respectively.

The galvanometer needle will now be deflected, and can be brought back to zero by turning the pointer Z either to the right or the left. Should, for instance, the pointer have to be brought to 30° on the A side, we have the following equation:

$$E_1 = E_0 \frac{150 - 30}{300 + u} \dots\dots\dots\dots\dots\dots (1)$$

where u is the resistance of the battery E_0.

The battery E_2 is now to be inserted in the place of E_1, and

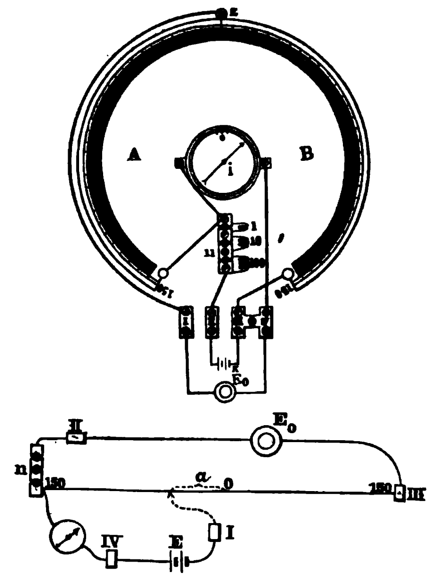


Fig. 150.

the galvanometer needle, when it deflects again, brought back to zero by moving the pointer Z. If, for instance, the pointer has to be pushed to 40° on the B side to obtain an equilibrium, we have

$$E_2 = E_0 \frac{150 + 40}{300 + u} \dots\dots\dots\dots\dots\dots (2)$$

By eliminating u from equations 1 and 2 we have:

$$E_1 \; E_2 : = (150 - 30) : (150 + 40) = 12 : 19 \dots\dots (3)$$

The two electro-motive forces are in the same proportion as the two observed distances of the pointer Z, from 150° on the A side of the instrument.

The lower diagram of figure 150 shows the arrangements of the circuits for comparing the electro-motive forces by this method. The more powerful battery E_0 is connected at II with one end of the resistance coils n, and at III with the other end of the resistance coil, through the bridge wire. The battery E is connected at IV with one of the termini of the galvanometer coil, whose other end is connected with one end of the bridge wire, and at I with the movable pointer or vernier Z. The current from E_0 enters the resistance coils at II and passes through them to the bridge wire, where two paths are open for its return —one *via* the bridge wire direct, and the other through the galvanometer, the battery E and the vernier Z to the bridge wire. The current from E enters the bridge wire near the resistance coils n and traverses the former until it reaches the pointer Z, whence it returns. By moving the pointer until the tension is the same at IV as it is at the junction of the bridge wire and the resistance coils n, no current will flow through the galvanometer.

DETERMINATION OF GALVANIC POLARIZATION.

It is evident that in the case of an element which contains liquids in its circuit, the actual electro-motive force of the element will be opposed by a new electro-motive force, which is caused by polarization (page 184), and consequently the actual strength of current S is longer obtained by Ohm's formula,

$$S = \frac{E}{W}.$$

If we indicate the sum of all the polarizations present in the circuit (*i. e.* their electro-motive force) by P, the resistance of the element and the metallic conductor by W, and the resistance of the liquid between the metallic conductors by F, then we obtain for the actual strength of current the expression

$$S = \frac{E - P}{W + F}$$

the correctness of which has been ascertained by the most varied tests made by including liquids in the circuit.

As the resistance of a liquid (F), and the polarization (P) which is caused by it, are entirely independent of each other, and as two liquids may very possibly present an equal resistance and still produce very different polarization, it follows that we should not imagine that a column of liquid will be absolutely replaced by the substitution of a metallic wire of corresponding resistance. When we substitute an equivalent metallic resistance for the line resistance, no attention is paid to the polarization. This, however, should be done when we want to know the exact strength of current.

For example, if we take the liquid column out of the circuit, and replace it by a wire which offers the same resistance, F, as the liquid, then we get for strength of current, since the polarization has been taken out with the liquid,

$$S_1 = \frac{E}{W + F},$$

while the strength of current with the liquid in circuit was

$$S = \frac{E - P}{W + F}.$$

It is evident, however, that S_1 is only equal to S, when $P = 0$. Consequently a liquid column can only be replaced by an equivalent wire resistance when the polarization produced by the liquid is infinitely small.

If this supposition is not admissible, we must ascertain the amount of polarization (P) previous to the reduction of the liquid resistance. This is done in the following manner:

A constant battery is joined up in circuit with a galvanometer and rheostat, sufficient resistance being unplugged to give a convenient deflection. Call the strength of current S. An additional resistance, r, is then introduced and the strength of current S_1 noted. The resistance r is now replaced by the liquid column whose polarization is to be determined, and the rheostat

adjusted until the strength of current is again equal to S, after which a new resistance, r_1, is added to reduce the current to S_1, as before; calling the electro-motive force of the battery E, the counter electro-motive force of polarization P, the total resistance of the battery, galvanometer and first inserted resistance W, and the resistance of the liquid F, we obtain from Ohm's law the following four equations:

$$1)\quad S = \frac{E}{W};$$

$$2)\quad S_1 = \frac{E}{W + r};$$

$$3)\quad S = \frac{E - P}{W + F};$$

$$4)\quad S_1 = \frac{E - P}{W + F + r_1};$$

From which we may easily determine the value of P; by combining equations (1) and (2) we find

$$E = \frac{S\,S_1}{S - S_1}\,r;$$

and from equations 3 and 4,

$$E - P = \frac{S\,S_1}{S - S_1}\,r_1;$$

whence

$$P = \frac{S\,S_1}{S - S_1}\,(r - r_1).$$

So that the difference of the resistances $r - r_1$ represents the polarization caused by the liquid. It is hardly necessary to add that the strengths of current S and S_1 are respectively the tangents of sines of the angles of deflection of the galvanometer needle.

In this way Lenz and Saweljev have found the polarization of the following combinations:

Platinum plates in nitric acid	538
" " sulphuric acid (6 parts concentd. sulph acid to 100 parts water)	1185
Amalgamated zinc plates in sulphuric acid	217
Copper plates in sulphuric acid	466
Tin " "	315
Iron " "	72
Graphite " concentrated nitric acid	273

While the values of polarization of

Copper plates in sulphate of copper is only	15
Amalgamated zinc plates in sulph. acid is only	6
Copper plates " "	2

As there is no gas given off at the metallic plates in the three last cases, these results prove that when the plates are not covered with a layer of gas, polarization does not take place. The small values given for the counter electro-motive force of polarization in these cases probably do not result from polarization at all, but rather from the fact that the plates themselves do not remain altogether unaffected during the course of the experiment, in consequence of which a new but insignificant counter electro-motive force is produced.

In the first of the preceding cases, with platinum plates in nitric acid, no hydrogen deposit is found upon the negative plate. The value 538 is consequently due to the polarization of the positive plate, and therefore to the one on which oxygen appears. According to this, 538 is the quantity of polarization produced by a platinum plate when covered with a layer of oxygen.

If we consider that the electro-motive force of a Daniells element is only 470, and that the counter force of polarization in the analyzing cell is as great, or even greater, which is often the case, it is easy to understand why it is not possible to produce a powerful decomposition except by means of the more powerful electro-motive force of a Grove or Bunsen element.

Polarization increases with the duration and strength of the current, until it reaches a certain maximum. An increase in the temperature of the liquid diminishes the polarization.

CHAPTER XXII.

TELEGRAPHIC CIRCUITS.

It has already been explained that a battery is an arrangement for generating currents of electricity, the action of which is to separate the positive and negative electricities and force them towards two opposite points, where they tend to re-unite. This re-union takes place as soon as the points of accumulation, or, in other words, the poles of the battery, are connected by a metallic wire or other conductor of electricity. The two electricities traverse the conductor in opposite directions with immense velocity; a velocity which varies according to circumstances, from 13,500 to 62,000 miles per second.

It has been proved, both in theory and practice, that the electric current possesses the same strength at every point throughout the circuit, irrespective of variations in the resistance of the conductor through which it passes, provided the latter is well insulated and there are no branch circuits. Hence the effects of any change, whether of electro-motive force, resistance, or arising from any other cause, must necessarily extend over the entire line. An increase or decrease of current in one particular part of the circuit can never therefore take place in a single complete line. As we must convey the current of a battery to and from a distant station in order to make its influence manifest at that station, it is usual to speak of two lines, one going and the other returning. When a current is to be transmitted both must necessarily be united in a continuous whole. The line may, however, consist of two or more unequally conducting parts; for instance, it may be partly of copper and partly of iron, or of moist earth, water, &c. In this case the bad conductors weaken the current in every part of the

entire circuit. When a telegraph line consists partly of iron wire and partly of moist earth or water, the weakening of the current, caused by the bad conductors, may be prevented, if the sectional areas of these conductors are increased in the same proportion as their resistances.

When Steinheil, in 1838, was making some experiments on the Nürnberg-Fürther railroad, for the purpose of determining whether the track could be used for telegraphic purposes, he noticed that the current passed from one of the rails to the other through the earth, and the thought occurred to him whether it might not be possible to use the ground itself, and in this way dispense with half of the metallic circuit. This proved to be feasible, and he was thus enabled thereafter to work his line with a single wire.

The discovery by Steinheil that the earth may serve as a conductor for the galvanic current is justly regarded as one of the most important discoveries in the art of electric telegraphy ever made, and it is one which has contributed very largely towards the extensive development of telegraphic lines. It is not easy to determine whether the earth really conveys the current in the manner of an ordinary conductor, from one station to another, or whether it should be regarded merely as a reservoir into which the electricities of the battery pass. While reserving further remarks respecting the solution of this problem for future consideration, we wish for the present to accept Steinheil's opinion that the earth is a conductor, and that the current actually passes through it from one station to another, in order that what follows may be better understood.

Steinheil speaks as follows concerning his discovery:

"We can form equally good conductors from so-called poor conductors, such as the earth, water, etc., as from the metals themselves, provided we increase their sectional area in the same proportion as their specific resistance.

"Suppose water to be 100,000 times as poor a conductor as copper, then a conductor may be made of water which shall not offer any more resistance than the copper, provided its sectional

area is made 100,000 times as great. But in order to obtain so large a sectional area of the poor conductor it is necessary to make the line terminate in metallic plates of the required dimensions."

Fig. 151 illustrates the plan for a complete circuit with the earth forming part. S S_1 are two corresponding telegraph stations, B is the battery, and A a telegraph instrument. The copper or iron line wire, L, proceeds from one pole of the battery to one terminal of the instrument A, while the other pole is in metallic connection with the earth or ground plate P. The second terminal of the instrument is connected to the earth

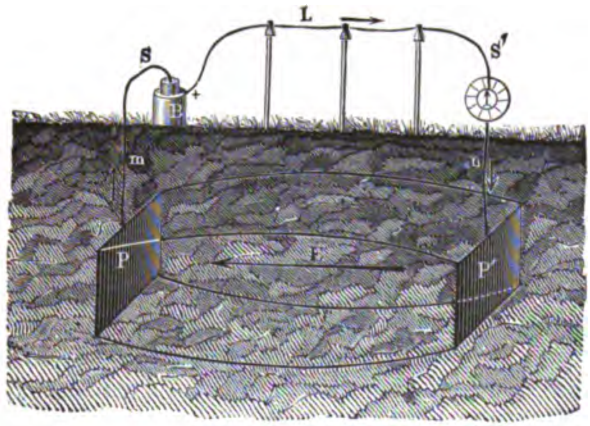


Fig. 151.

plate P′. The earth plates are made of zinc or copper, exposing about 20 square feet of surface, and are sunk in moist earth, in a spring, or in the bed of a river. As long as an interruption exists anywhere in the circuit, P *m* B L A *n* P′, no current can circulate, even when the wires *m* and L are connected with the poles of the battery. When, on the other hand, the circuit is completed, the battery is said to be closed, and the current flows in the direction of the arrows; that is, starting from the + pole of the battery it passes through L to S′, traverses the instrument A, and proceeds to the earth plate P′. From here it

passes through the damp earth in the same manner as if the latter were a metallic wire, but in consequence of the very great sectional area of the earth, the current passes much more freely than it would through a second wire. From the opposite plate P of station S it passes to the — pole of the battery, thus completing the circuit. If we were to replace the stratum of earth E by another wire whose resistance equals that of the wire L, we should find that the resistance of the complete circuit would be almost twice as great as when using the earth as a conductor, because the latter offers scarcely any resistance at all; consequently, with the second wire the strength of current would be reduced nearly one half, or, to get the same strength of current as at first, we would be obliged to use a battery of nearly double the power.

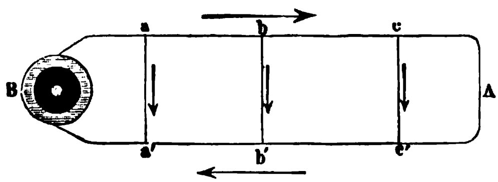


Fig. 152.

In using the earth as a conductor, therefore, not only is half of the metallic conductor dispensed with, but there is also a considerable gain in the actual strength of current, and a much smaller battery may, therefore, be employed.

ESCAPES OR DERIVED CIRCUITS.

Although it appears at first sight a matter of little difficulty to construct such a line as we have described, the difficulties attending it in practice are very numerous.

When two wires, *a b c*, *a′ b′ c′*, starting from the battery B, and running near each other, come in contact at any point, or are connected by cross wires, *a a′*, *b b′*, *c c′*, as represented in fig. 152, the current produced by the battery will not have the same strength in all parts of the wire, *a b c*, *c′ b′ a′*, and, therefore, it will not produce the effect at A that it would were these

cross connections not present. As the current is also greatest in circuits of the least resistance, which in general are the shortest ones, a considerable portion of the current would pass through cross wire $a\ a'$, completing its circuit by the route B $a\ a'$ B. A portion of the remaining current would also pass through $b\ b'$, and its circuit would consequently be through B $a\ b\ b'\ a'$ B.

It appears, therefore, that the effective current at A will be less as the cross connections between the wires become more numerous, and that the strength of current between B and A gradually decreases in proportion to the number of these so-called derived circuits $a\ a'\ b\ b'\ c\ c'$. It is also evident in this case that the strength of current at A will become less as the conductivity of the derived circuits is more considerable, and that in certain cases, when the resistances of the derivations are very small in proportion to that of the entire line, no current at all will be perceptible at A.

CONDUCTIVITY AND INSULATION OF THE LINE.

Special care should be taken in constructing a line to have every part of it properly insulated. Conductivity is the first requisite in a telegraph line. The greater number of interruptions which so frequently occur, especially on long lines, are attributable to the imperfect conduction which results when the line is not well insulated in every part. The insulation of telegraph lines becomes more difficult as the number of wires increase; but it is practically impossible to construct a line so as to do away with escapes or derivations entirely, even when using but two wires, or one wire with the earth to complete the circuit.

Two things, therefore, are required of a good line. In the first place, it must transmit the current as freely as possible and oppose to it the smallest possible resistance. This quality of a conductor is called its conductivity. In the second place, the conductor should be insulated as perfectly as possible to prevent any escape of the current.

Secondary to the principal qualities of conductivity and in-

sulation, in building a telegraph line, should be the consideration of its strength, durability and cost.

Since the general knowledge of Steinheil's discovery that the earth may be used as a conductor, only a single wire has been employed in the construction of telegraph lines of any length. This is equally true in the case of land lines, underground lines and submarine lines. There are, however, a certain class of telegraph lines, upon which the use of a complete metallic circuit, entirely insulated from the earth, is found to possess many advantages over the arrangement above described, in which the earth forms a part of the circuit. An example of this is found in the municipal fire alarm telegraph, so extensively employed in the principal American cities. In this form of telegraph the lines all radiate from a central station, each line connecting with a number of signal boxes situated in a certain section of the city. Thus a line may go out from the central station by one route and return by another, each route accommodating the stations in a distinct portion of the city. The length of wire required by this arrangement is but little greater than would be the case if the earth formed part of the circuit, while the advantages secured are of much importance. In case of a breakage of the wire the circuit may be completed through the earth until the break is repaired, and what is perhaps of even greater importance, an accidental contact with the earth or with another wire will seldom interfere with the proper working of the lines. Another advantage arises from the fact that when a line is entirely insulated from the earth its liability to interruption and injury from the effects of atmospheric electricity is very greatly diminished.

CHAPTER XXIII.

LAND LINES.

THE first land line of telegraph appears to have been built by Professor Weber in 1833, mainly for the purpose of experimenting in an extended manner upon the laws regulating the strength of currents under different circumstances. The line consisted of two wires connecting the Observatory of Gottingen with the Cabinet of Physics, and was about 6,000 feet in length. Four years later Steinheil constructed a telegraph line between the Royal Academy in Munich and the Observatory in Bogenhausen, a distance of three miles. Both wires were stretched from three to ten feet apart over the steeples of the city. In places where there were no high buildings the wires were attached to cross-arms, supported by poles set in the ground. The poles were between forty and fifty feet in length, and the distance between them from 600 to 800 feet. Felt was used to insulate the wire at the points of support. Steinheil very soon discovered that his conductors were imperfectly insulated. When the wires were separated at Bogenhausen and an induction current was produced in Munich, the Gauss galvanometer, which was inserted in a separate part of the line, showed the passage of a weak current. The felt and wooden supports permitted the escape of the current, and this difficulty was, of course, greatly increased when the felt and supports became wet by rain. The first line constructed in England, in 1839, extended from Paddington station, London, to West Drayton, a distance of a little more than thirteen miles. It was composed of six copper wires enclosed in a wrought iron tube an inch and a half in diameter, and six inches above the ground, which was laid alongside the railway. The wires were insulated from each other, within the tube, by a covering of hemp. In 1842, William Fothergill

Cook adopted the method of placing the wires on poles, and then of insulating them by threading them through conical supports of stone or earthenware, and this method, with various modifications, has been largely employed in England. The first lines put up in the United States, in 1844 and 1845, extending from Washington to New York and Boston, were of No. 16 copper wire, insulated at the points of support by means of cloth saturated with gum lac.

WIRE.

A very short experience with copper line-wires, both in this country and in Europe, proved that this metal was altogether unsuitable for the purpose, its sole recommendation consisting in its superior conductivity, and it was, therefore, soon replaced by iron wire of larger diameter. As we have seen by the table on page 176, the specific electrical resistance of iron is about six times as great as that of copper. It is only necessary, therefore, to increase the sectional area of the iron wire to about six times that of copper, or, in other words, to make its diameter 2½ times greater, to attain an equal conducting power. The strength of such an iron wire is about twelve times that of the copper wire which it replaces, while its cost is no greater. For these reasons iron wire is now used almost without exception for telegraph lines in all parts of the world. The sizes employed vary in different countries, and according to circumstances, from No. 11 (Birmingham gauge), weighing about 200 lbs. per mile, up to No. 4, weighing nearly 800 lbs. per mile. The wires most frequently used are those weighing from 300 to 400 lbs. per mile.

The best wire is made from pure charcoal iron, which, after having been drawn, possesses a high degree of toughness, especially if annealed, and when broken discloses a fibrous structure. It has been shown by repeated experimental tests that the best quality of wire now to be had is that made from the purest Swedish charcoal iron.

When plain or unprotected iron wire is stretched in the open

air and exposed to the action of the elements, it loses in the course of time not only a considerable portion of its strength, but its conducting power is also materially lessened. This effect is owing to the oxidization or rusting of the wire, and is much more marked in cities and along the lines of the principal railways than elsewhere, in consequence of the atmosphere being impregnated with the acid gases arising from the combustion of coal. Small wires also decay much more rapidly in proportion than large ones. In some localities, notably in the cities of Pittsburg and Wheeling, a plain No. 9 iron wire is rendered almost worthless in a very few years, while, on the other hand, there are wires of this kind still in use on some of the routes of the New England States, put up in 1847 (twenty-eight years ago), which are still in very good condition, and doing excellent service. Indeed, some sections of the lines, remote from the sea-coast, show very little evidence of decay after twenty-five years' exposure.

Fig. 153.

In order to prevent as far as possible the decay of the wires arising from this cause, the plan of immersing them while red hot in linseed oil, before erection, was formerly employed to some extent, but it is now the almost invariable practice, in all parts of the world, to use galvanized or zinc coated wire, which, although somewhat expensive, is under most circumstances very durable.

The method of jointing the line-wire which is in general use in the United States is that known as the common twist joint, and is shown in fig. 153. The end of each wire is closely turned around the other four or five times, and the ends cut off short. The joint is then dipped in melted solder, or has the solder poured upon it, the former method being preferable.

POLES.

Wooden poles are used almost exclusively for telegraphic purposes in nearly every part of the world. The principal ob-

jection to these is, of course, found in their rapid decay by exposure to the elements. In Europe it is a common practice to prepare the poles by impregnating them with various preservative compounds, which enables them to resist for a much longer period the injurious effects of exposure. In some cases the preservative substance is poured over the poles in large quantities, and left for a long time in contact with them. In other cases it is forced into the pores of the wood by hydrostatic pressure, or the impregnation is effected in closed boilers, a vacuum and a heavy pressure being alternately produced by means of pumps. The preservative substances employed are as various as the methods of impregnation; the principal ones are sulphate of copper, chloride of zinc, creosote and coal tar. It has not, thus far, been found economical to employ any process of preserving poles on the lines of the United States, in consequence of the comparative abundance and cheapness of excellent timber. Owing to the superior quality of the timber available in this country, it is found that the average life of our unprepared poles is fully equal to that of the prepared poles used in Europe.

Iron poles are coming somewhat into use in many of the countries of Europe and Asia, and also in South America, and it is probable that their employment will hereafter become very common in many countries where good timber is not to be had, or where it is rapidly destroyed by climatic or other influences. They have not as yet been used to any considerable extent in the United States.

In some portions of the United States, as well as in Switzerland and in the island of Java, living trees have been made available over large tracts of country as supports for telegraph wires. The brackets for the insulators are attached to the trunks of the trees, and the branches so far cut away that, even in a heavy gale, there will be no danger of their coming in contact with the wires. A line may be very quickly and cheaply constructed in this manner, and has in many cases been found to answer very well as a permanent line, especially when trees of a

suitable character are planted along the route at convenient intervals, as has been done in Austria and in Java. When put up in this manner, however, the wire is very easily broken by the repeated bending which is caused by the swaying of the trees during heavy winds, and it has, therefore, been found necessary to use a specially arranged insulator to avoid this difficulty.

Fig. 154 represents an arrangement devised by Lieut.-Col. Chauvin, formerly Royal Prussian Director of Telegraphs, which allows the tree to move freely without interfering with the wire.

Fig. 154.

The upper end of a permanent iron carrier is screwed into the tree, the lower end being fastened by a strong wood-screw. The insulator is suspended from the eye of the carrier by an iron rod, and the wire hook is cemented into the bell of the insulator, and bent outwards so that it cannot be turned over. Experience has shown that this device answers its purpose admirably. The method of attaching wires to trees which is employed in America is much simpler than the above, but has been found to serve well. It will be described hereafter in connection with other American modes of construction.

It frequently happens that the erection of poles in certain localities, especially in the streets of cities and villages, or in the vicinity of railway stations, is attended with considerable inconvenience and difficulty. In such cases, or when specially strong supports are required, the insulators are frequently attached to buildings, either directly or by means of wrought iron standards. Fixtures of this kind are often used with advantage in carrying the wires across long bridges.

INSULATORS.

The most difficult problem in practical telegraphic construction is unquestionably that of the effectual insulation of the wires from each other and from the earth. Some of the earlier methods which were tried for this purpose have already been referred to. The progress of invention in respect to insulation followed substantially the same course in different countries. In the United States glass insulators first began to be used about the year 1846, and, in one form or another, have continued to be more generally employed than any other from that time until the present. In England and on the Continent earthenware and porcelain have generally been preferred to glass as a material for insulators, although the latter is used almost exclusively in Switzerland. All these insulators are made more or less concave upon the under side, in order to prevent the formation of a continuous conducting line of water between the line-wire and the support of the insulator.

The following are the most essential qualities of a good line insulator: The material of which it is composed must itself be possessed of high insulating qualities, and should not be subject to decay or deterioration from long continued exposure to the weather. The surface must be repellant of moisture, and not liable to retain dust or smoke. The form should be such as will interpose the greatest possible insulating distance between the line wire and the cross-arm or pole, which is compatible with the necessary mechanical strength for supporting the wire.

The insulators in use at the present day in different parts of

the world are principally the following: plain unprotected glass, and glass with an iron covering; vulcanized rubber; brown earthenware, glazed, sometimes in combination with vulcanized rubber; white porcelain; and baked wood, prepared with some resinous compound.

Of these the unprotected glass is now more extensively used in America than any other. The principal objections to it are the property it possesses of becoming covered with a film of moisture in certain states of the atmosphere, and its liability to fracture. The first of these is practically much more serious than the other, and thus far no effectual means of overcoming it has been discovered. The iron-protected glass insulator is open to the objection that when a defect occurs it is very difficult to discover it, and a single defective one will often seriously interfere with the operation of the line. It is used to some extent in the United States, as is also the baked wood insulator. The vulcanized rubber insulator, from its convenient form and great mechanical strength, is much used on short lines, and especially in cities. Its insulating qualities after a few years' exposure are not very high, but this is relatively of less importance than the other qualities mentioned, in the particular class of work for which it is most used.

In England the brown earthenware insulator is principally used, and is there regarded as superior to the glass insulator, but comparisons made in this country do not appear to confirm this opinion. Tests made in different parts of the United States, and by different experimenters, have uniformly shown that the insulating qualities of the glass surpassed those of the earthenware. The large white porcelain insulators used on the continent of Europe, appear to be superior to those of glass or of earthenware, but are quite expensive, and this fact, perhaps, as much as anything else, has prevented their more general use in other countries.

We shall now describe, in a more detailed manner, the methods of constructing land lines which have been adopted in different countries, and in the same connection the different methods of

insulation that are used in these countries will be further referred to.

CONSTRUCTION OF LAND LINES IN THE UNITED STATES.

The lines in this country at the present day are in almost every instance constructed along railway routes, where such routes exist, although in the more sparsely settled portions of the country there are still a considerable proportion of the lines built along the highways.

The kinds of timber used for poles in America are principally the chestnut, white and red cedar, and red wood. The locust, oak, and cypress are also used to a limited extent. In that section of the United States lying east of a line drawn from Cleveland, Ohio, to Wilmington, N. C., the chestnut is almost exclusively used, with the exception of a tract along the southern shores of Lake Erie and Lake Ontario, where the white cedar is employed, as it is almost without exception in the Dominion of Canada. North of the Ohio river, and west of the above mentioned line as far as the Rocky Mountains, scarcely any timber but the white cedar is employed, while south of the Ohio by far the largest portion of the lines are constructed with poles of red cedar. On the Pacific coast the red wood and Oregon pine are employed, one large tree being frequently sawn into a great number of square poles. The chestnut is tough and elastic, and its durability under average circumstances is estimated to be from twelve to eighteen years, without other preparation than thorough seasoning. The durability of the white cedar is nearly equal to that of the chestnut, and in some soils it even surpasses it, but the wood is inferior in strength and toughness to the former, being of a more brittle character. The red cedar, although a rather unsightly variety of timber, is perhaps more indestructible than any other. It has been known to remain in a good state of preservation for more than twenty-five years.

At the present day few or none of the lines erected in this country are supplied with poles of length less than twenty-five

feet, with a diameter of at least six inches at the top. Poles of this size, if well set, are capable of carrying seven to nine wires of the ordinary size. On the principal routes between the more important points, poles are used of lengths varying from twenty-five to forty feet, according to the requirements of the cases, while in the streets of cities they are often used from forty to sixty or seventy-five feet in length, and in some instances even ninety feet. They are stripped of their bark and smoothed, but are seldom painted, except where the line passes through a town or village.

The distance between the poles on the lines in different parts of the United States varies considerably, according to circumstances. Generally speaking, it is considered necessary to place them nearer together in the northern than in the southern portion of the country, on account of the great variations of temperature to which the wires are subjected at different seasons of the year, which are far greater than is the case in most parts of Europe. The difference between the extremes of summer and winter temperature (which in many of the northern States often ranges from 90° to —20° Fahr.) causes a variation of about four feet per mile in the length of an iron wire. This necessarily renders the lines very slack in warm weather, and in order to keep the wires well separated from each other, the poles are placed comparatively close together. They are seldom placed less than twenty or more than forty per mile in any part of the country, the average number being perhaps about thirty.

The cross-arms generally used are of well seasoned white pine, planed off and beveled on the upper corners, and painted with two coats of rubber paint. The best size is about four inches by five. The length, of course, varies according to the number of wires. For two wires it is usually three feet, for four wires, five feet six inches, and for six wires, seven feet six inches. The distance apart is ordinarily twenty-two inches between centres. It is the usual practice to place all the arms on the same side of the pole. Fig. 155 is an example of the standard style of con-

struction in the United States at the present time, where the glass insulator and wooden pin is employed.

The lines in the central portion of the United States have always been greatly exposed to danger from the effects of lightning, but it is not until within a few years that any efficient means of protecting them has been adopted. The plan of arranging the lightning conductors which has given the most satisfactory results is that illustrated in fig. 156.

It will be seen that this plan avoids any liability to interfer-

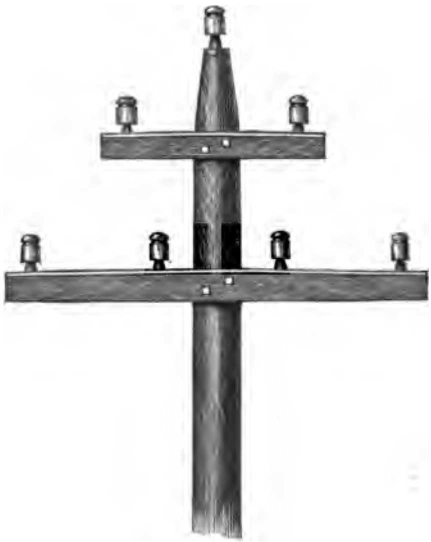


Fig. 155.

ence from accumulations of snow and sleet, and if the lightning rods are accidentally bent or displaced they cannot come in contact with the line wires. The side extensions or branches shown in the figure are not used except in the vicinity of the stations, where the arrangement serves to protect both the poles and the apparatus of the office.

Where a single wire only is placed upon a line of poles, it is the usual custom to fix the insulator upon a bracket spiked to the side of the pole near the top, as shown in fig. 157, or else

to place it upon a pin inserted in the top of the pole, as in fig. 155. In the former case the side of the pole is blazed off, in order to furnish a flat surface for the bracket to bear against, and the latter is secured to the pole by two strong spikes, as

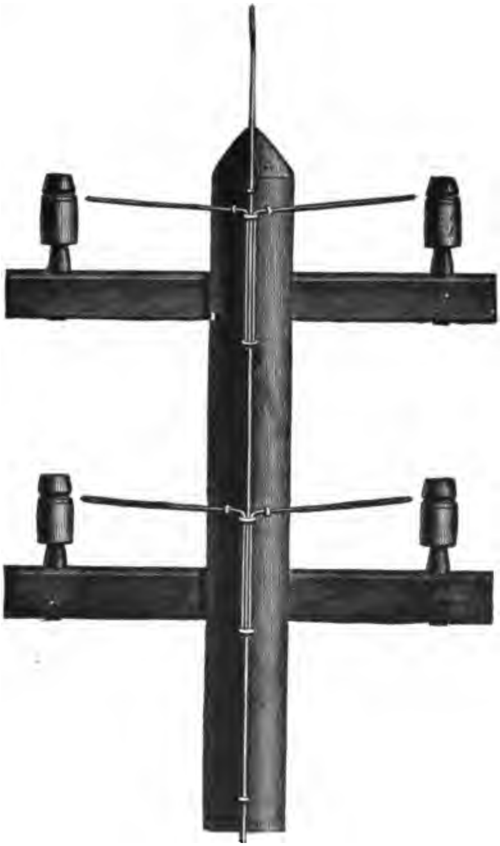


Fig. 156.

shown in the figure. The bracket is placed far enough below the top of the pole to insure the wire being caught, in case the insulator becomes broken. When the top pin is used, an iron ring is driven upon the top of the pole, which prevents the latter from splitting and the pin from becoming loose in its socket.

The wire used for telegraph lines in the United States is of iron, the most usual sizes being No. 9, weighing 323 lbs. per mile, and No. 8, weighing 389 lbs. per mile. Wire of a less diameter than No. 9 is scarcely ever used except for private lines, while of late years the tendency of telegraphic constructors has been to use larger conductors than heretofore. Many of the more important lines of the Western Union Company are now built of No. 6 wire, weighing 570 lbs. per mile. A compound wire of steel with an external covering of copper has also been employed to some extent. Galvanized or zinc-coated wire is almost universally employed, owing to its greater durability, though the tensile strength of the wire is somewhat diminished by subjecting it to this process.

Fig. 157.

The following table contains the results of a series of tests of different samples of iron wire of American manufacture, such as is used for telegraphic construction in this country. The column under the head of "Relative Breaking Strain," has been calculated from the actual breaking strain as given in the fifth column, and the weight per mile as given in the second column, and shows the number of feet of its own length that each sample would be capable of sustaining. The arrangement of the table, it will be noticed, affords an opportunity of comparing in adjacent columns the relative breaking strain and relative conductivity of each sample. The tests are arranged in the order of their relative breaking strain

Sample Mark and Gauge.	Mechanical.					Electrical.	
	Weight per mile, (lbs.)	Per cent. of Elongation.	No. of Twists, (6 in.)	Actual Breaking Strain, (lbs.)	Relative Breaking Strain.	Per cent. Conductivity, Pure Copper = 100.	Resistance per mile in Ohms at 60° Fah.
EBB. Galv. No. 12	190.83	11.5	14 16 } 15	430 405 } 417.5	11552.2	14.4	30.5
EBB. Galv. No. 8	381.66	17.7	24 29 } 26.5	945 930 } 937.5	12930.6	17.3	12.67
EBB. Galv. No. 11	222.64	17.2	21 22 } 21.5	575 580 } 577.5	13639.4	15.6	24.2
151. No. 9½	282.8	10	25 28 } 26.5	760 780 } 770.	14375.9	21.9	16.1
EBB. Galv. No. 10	254.44	17.7	28 29 } 28.5	675 720 } 697.5	14478.1	17.8	18.42
146. No. 9½	287.5	16	27 31 } 29	825 840 } 832.5	15288.86	21.9	16.1
EBB. Galv. No. 6	508.88	11.4	21 22 } 21.5	1585 1590 } 1587.5	16462.4	17.7	9.21
EBB. Galv. No. 9	318.05	19.3	17 18 } 17.5	1005 1010 } 1007.5	16725.1	16.9	15.54
Nashua " No. 8	381.66	15.1	25 28 } 26.5	1530 1540 } 1535	21183.	14.7	15
MS. Plain No. 6	528	10.4	18 21 } 19.5	2110 2165 } 2137.5	21375.	13.5	11.78
443. No. 8	378.1	10	29 33 } 31	1630 1640 } 1635	22301.4	16.5	16.1
A H. No. 9½	293.5	16	27 28 } 27.5	1255 1260 } 1257.5	22635.	15.1	22.7

It will be observed that in general the samples having the highest tensile strength stand lowest in respect to electrical conductivity, and *vice versa*.

The insulator used on by far the largest portion of the tele-

graph lines in the United States and the Dominion of Canada is a plain glass insulator, mounted upon a wooden pin or bracket, usually of oak or locust. Fig. 158 represents the standard insulator of the Western Union Telegraph Company, and its supporting pin, drawn to a scale of one third the actual size. Fig. 159 is a plan or top view of the same, which shows the manner in which the line wire is tied to the insulator at each pole. It will be observed that the insulator is constructed of such a form as to give the greatest possible length of insulating surface between the line wire and the supportin pin, in this

Fig. 158.

Fig. 159.

case nearly four inches, while at the same time it is of small diameter, as this not only increases the strength but diminishes the cross-section of the conducting surface of moisture, which, of course, follows the same law as any other conductor; the greater its length and the smaller its cross-section the higher is its resistance.

The insulator used in the Dominion of Canada is also of glass, and about the same size as the one just described. The lower part is usually expanded into a bell or umbrella like form. This is, however, both theoretically and practically a disadvan-

tage, as it increases the breadth of the conducting surface of moisture, and the thin, projecting flange is much more easily broken or injured by missiles, while no corresponding benefit results from its increased diameter.

The best glass insulators are now formed with a screw-thread upon the inside of the socket, which fits into a corresponding screw cut upon the wooden supporting pin, as shown in fig. 158, and thus the insulator is prevented from being drawn off from the pin by an upward strain or by the action of strong winds upon the wires. Sometimes the glass and pin are made plain, and the

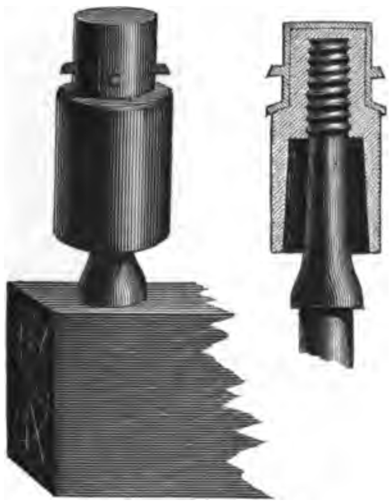


Fig. 160. *Fig.* 161.

two are secured together by cement, but this plan is inferior to the one first mentioned.

The liability of glass insulators to fracture, after having been placed on the line, is not so great as is generally supposed, although it is, of course, much greater in some localities than in others. The percentage of broken and defective insulators which were replaced on the whole extent of the lines of the Western Union Telegraph Company for four years, was as follows:

1870, ...	6.5 per cent.
1871, ...	6.2 " "
1872, ...	7. " "
1873, ...	6.1 " "
Average, ...	6.4 " "

For several years past the insulator shown in figs. 160 and 161 has been employed in several of the north-western States, especially upon the lines of the Northwestern Telegraph Company. Its form is quite similar to that of the most approved model of the glass insulator, but the material of which it is composed

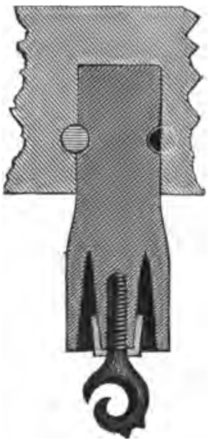


Fig. 162.

Fig. 163.

is white-wood, baked, and impregnated with a non-conducting compound, which gives the surface of the insulator a glossy surface, highly repellant of moisture. The upper part of the insulator, to which the wire is tied, is protected by an iron cap. Another form of the same insulator, arranged in such a manner as to hold the wire by suspension, is shown in figs. 162 and 163. The engravings show clearly the manner in which these insulators are constructed and attached to the cross-arm, and also the method of securing the line wire to them.

Fig. 164 is a sectional view of the vulcanized rubber insulator in its most approved form. The upper portion or stem of the iron hook for holding the wire is enveloped in an insulating coating of vulcanized rubber, which has a thread cut upon it,

Fig. 164.

so that it may be screwed into a cross-arm or other convenient support. Its insulating qualities deteriorate very seriously after exposure to the weather for some time, and it is now but little used for lines of considerable length. For short lines, especially

Fig. 165.

in cities, it answers an excellent purpose, as it is very strong, weighs but little, and can be used in almost any situation.

Fig. 165 is a sectional drawing of the paraffin insulator, which

is used on some of the railway telegraph lines in the United States. It consists of an outer shell, or casing of iron, in the form of an inverted cylinder, open at the lower end. A narrow necked inverted bottle of blown glass, of similar form, is cemented within it—and inside of the latter is secured by the same means an iron stem, carrying a hook at the lower end, by which the wire is supported. The surface of the cement, both within and without the glass bottle, is coated with paraffin. The whole is inserted into a hole bored in the under side of the cross-arm, in the same manner as the insulator shown in fig. 162, the line wire passing beneath the insulator and the cross-arm.

The lines running through the sparsely settled and forest covered regions of the south-western States are frequently fitted with an insulator known as the "square glass," which has been in use for this class of lines ever since 1846. Although much less perfect in its insulating qualities than many others, it is practically indispensable under the peculiar circumstances which attend the maintenance of lines in the portions of the country to which we have referred.

Fig. 166 is a perspective drawing of the square glass insulator, which is a little more than three inches in length. A longitudinal aperture passes through the glass, about half an inch in diameter in the centre, expanding to an inch at each end. The wire is dropped into this through a narrow longitudinal slot on the upper side, which has an angle in it, as shown in the figure, in order to prevent the line wire from being drawn out by an upward strain. The sides and bottom of the glass are provided with projections which hold it in its place when it is inserted in a cross-arm, as shown in fig 167. A notch of suitable size and shape is cut in the upper side of the arm, the insulator and wire are put in their places, and a piece of board is then nailed over the top to serve as a roof. Fig. 168 shows the manner in which this insulator is fitted to a bracket, for attachment to the trunk of a living tree. The advantage derived from the use of this insulator in a forest covered territory is, that if a tree falls across the line the wire will not be broken,

but will be carried down with the tree, and the strain will merely cause the slack to be taken up for some distance on each side. The wire passes freely through the insulators, not being fastened to them in any manner, and as it seldom actually touches the ground, the communication is rarely interrupted. The degree of insulation obtained is considerably higher than would be supposed at first sight, for the reason that the surface of contact between the wire and the glass is much less than in the ordinary forms, and this serves in a great measure to compensate

Fig. 166.

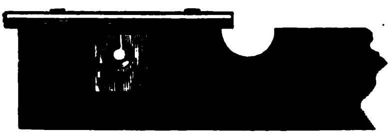


Fig. 167.

Fig. 168.

for its disadvantages in other respects. With any of the ordinary insulators, it would be quite impossible to keep a line working in some parts of the country for any considerable portion of time, owing to the numerous interruptions arising from falling trees. The square glass insulator also allows the trees to which the line is attached, as in fig. 168, to sway in the wind without danger of breaking the wire.

In many of the large cities of the United States, especially in

New York and Boston, a large number of the lines are carried over the house tops on fixtures or standards erected upon the roofs for that purpose.

Fig. 169 shows a form of fixture which has been for many years extensively employed in New York, and is found to answer an excellent purpose. It is well adapted for any number of wires not exceeding nine. The upright standard is of

Fig. 169.

pine, about ten feet in length, and fitted with two cross-arms of the usual description, which carry the insulators. The lower cross-arm is usually about seven feet above the roof. The upright is strongly braced on three sides by rods of $1\frac{1}{8}$ inch iron, fastened to the roof by lag-screws. Angle-irons are also attached by lag-screws to the foot of the upright and to the roof, as

shown in the figure. Near the lower end of each of the iron braces a circular collar is formed, in the manner shown in the figure. To prevent leakage of water through the roof during wet weather, the foot of the upright, including the angle-irons as well as the foot of each of the braces, is carefully sheathed over with tin, and afterwards painted, the sheathing being carried close under the collars of the braces, so that during rain the water which flows down the latter drops off from the edge of the collars, and therefore cannot penetrate underneath the sheathing.

These fixtures are erected on the tops of the most prominent buildings along the route selected, usually upon roofs sheathed with tin, and nearly flat, at an average distance of some 300 feet apart. Owing to the great rigidity and firmness of the supports, the spans may be made much longer, without danger of accidental contact between the wires, than would be advisable in the case of a pole line. Where it becomes necessary to place a large number of wires, say forty or fifty, upon one over-house route, as is sometimes the case in the vicinity of the principal office in a large city, two or three uprights are employed for each fixture, and these are connected by cross-bars. The whole structure is then attached to the roof and braced in the same manner as the smaller fixture previously described.

CONSTRUCTION OF LAND LINES IN ENGLAND.

The construction of the English telegraph lines is uniformly excellent, and reflects great credit upon the engineering staff, in whose hands the work is placed. As a rule, the great railway routes, where the principal lines are built, are straight and level, and free from trees, so that there are no natural obstacles in the way to prevent the construction of well formed and symmetrical lines, and the engineering staff has not failed to take advantage of every opportunity to make a handsome as well as strong and durable structure.

The timber used for poles is generally larch, treated with sulphate of copper, and red fir creosoted. The following table

gives the specified sizes of the red fir poles used upon the English lines:

LENGTHS AND SIZES OF RED FIR POLES USED IN THE POST-OFFICE TELEGRAPHS.

No. 1 Size—Light Poles.			No. 2 Size—Stout Poles.		
Length in Feet.	Minimum Diameter at Top.	Minimum Diameter at 5 Feet from Butt End.	Length in Feet.	Minimum Diameter at Top.	Minimum Diameter at 5 Feet from Butt End.
20	5 inches.	6½ inches.	22	5½ inches.	7¾ inches.
22	5 "	6¾ "	24	5½ "	8 "
24	5 "	7 "	26	5¾ "	8¼ "
26	5 "	7¼ "	28	6 "	8¾ "
28	5 "	7¾ "	30	6 "	9 "
30	5 "	8 "	32	6¼ "	9¼ "
32	5¼ "	8¼ "	34	6¼ "	9¾ "
34	5¼ "	8¾ "	36	6½ "	10 "
36	5½ "	9 "	38	6½ "	10¼ "
38	5½ "	9¼ "	40	6½ "	10¾ "
40	5½ "	9¾ "	45	6¾ "	11½ "
45	5¾ "	10½ "	50	7 "	12¼ "
50	6 "	11¼ "	55	7¼ "	13 "
			60	7½ "	13½ "

The light class is generally used for lines up to seven, or even nine wires. On railways, where stays can be freely used, the light poles are strong enough to carry more wires than the above quoted numbers. For heavily wired highway lines, and for all canal lines, where, on account of frequent and sharp curves, there is great lateral strain, the stout class is used. The length is, of course, determined by the number of wires, distances apart vertically, and headway required under the wires. The usual height of lowest wires on road lines is from fourteen to sixteen feet, and when they pass over roads or field gates eighteen to twenty feet. On canals, where they are less exposed to mischievous interference, they are kept lower. The longer lengths, say thirty-six feet and upwards, are required for long spans or for clearing buildings, etc.

The creosoting is accomplished by the Bethel process. The poles are placed in an iron receiver and the air exhausted from them, after which boiling creosote oil is forced into them by

pressure. This process greatly increases the durability of the wood, pine and spruce being thus rendered as lasting as cedar. The odor of creosoted poles in some places is said to be offensive, but no objection is raised against them in England on this account.

The following table will give the particulars as to the size and cost of the creosoted poles:

Average Length.	Class.	Diameter at Top.	Diameter at 5 Feet from Bottom.	Quantity of Oil per Cubic Foot.	Original Cost of Pole.	Dressing, Inspecting, etc.	Creosoting.	Total Cost.
24 ft.	medium.	5	7	8 lbs.	6*s.*	1*s.* 1*d.*	2*s.* 6*d.*	9*s.* 7*d.**
26 ft.		5	7½	8 lbs.	6*s.* 6*d.*	1*s.* 2*d.*	2*s.* 9*d.*	10*s.* 5*d.**
26 ft.	stout.	5¾	8½	8 lbs.	8*s.* 4*d.*	1*s.* 2*d.*	3*s.*	12*s.* 7*d.*†
28 ft.		6	9	8 lbs.	10*s.* 10*d.*	3*s.* 3*d.*	3*s.* 3*d.*	15*s.* 6*d.*†

The poles are never creosoted until they have been stacked a sufficient length of time to be thoroughly dry.

The cost of creosoting includes a certain margin for loading into trucks, or on board ship, which is always stipulated for when the contracts are made.

It sometimes happens that a parcel of poles are exceptionally dry, in which case they are given an extra two pounds of oil per cubic foot, costing from sixpence to eightpence per pole additional.

When poles are used which are neither prepared with sulphate of copper or creosote, they are well seasoned, and then painted, the butt ends being slightly charred from the bottom to a foot above the ground line, and tarred.

The cross-arms are made of English oak, two inches thick and twenty-four and thirty-three inches in length, and are placed alternately on either side of the pole. A twenty-four inch cross-arm is placed on the front of the pole a foot from the top, and then a foot lower down a thirty-three inch cross-arm is placed

* For lines carrying not more than six wires.

† For lines carrying seven to fifteen wires.

on the back of the pole, and so on. In some cases as many as seventeen wires are carried upon a single line of poles of twenty-five feet in length, and no cross-arm carries more than two wires, except upon the double pole lines, where seven foot cross arms are employed, and four wires are supported upon each cross-arm.

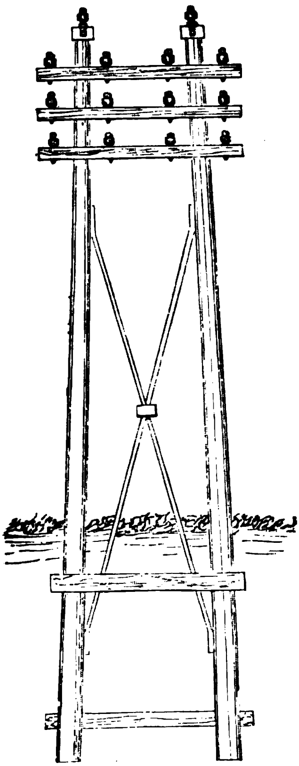


Fig. 170.

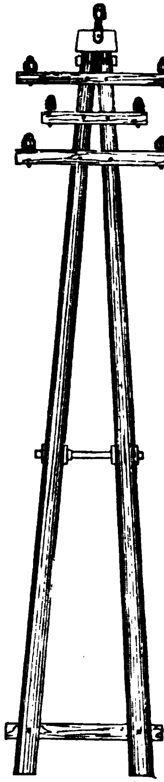


Fig. 171.

In the case of double pole lines, the two sets of poles are placed about three feet apart and framed together so as to support each other, seven foot cross-arms extending across and being attached to both poles at the upper end, as shown in fig. 170. These lines are generally to be found upon the canals,

but rarely upon the railways, except near large towns, where a great many wires converge.

The arrangement shown in fig. 171, and commonly known as the A pole, consists of two poles slightly scarfed at the tops, and fitted together as an isosceles triangle, with an iron cross-tie about eight feet from the ground, and a wooden brace at the base of the structure, below the ground. The object is to give the greatest possible rigidity where a narrow base is imperative.

All the poles are provided with earth wires or contact con-

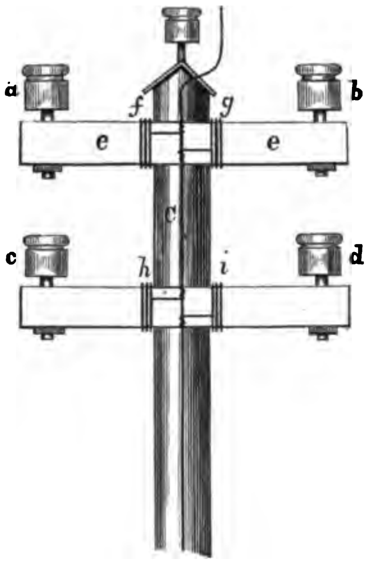


Fig. 172.

ductors for carrying the wet weather escape directly to the earth, instead of permitting it to leak into the neighboring wires. The manner in which these are arranged is shown in fig. 172. The earth wire consists of a piece of No. 8, galvanized iron wire, extending from six inches above the top of the pole to the bottom, and terminating in a flat coil attached to the foot of the pole, so as to expose as large a surface as possible to the earth. From the thick earth wire branches, composed of No. 10 galvanized

iron wire, are carried in saw-grooves sunk in the cross-arms, and soldered to the insulator bolts. Thus, any current escaping from *a* along the wet arm *e*, on arriving at *f* finds a good easy channel down the wire C to the ground.

Any electricity which may pass *f* is arrested at *g*, *h* or *i*, and taken away before disturbing the working of *b*, *c* and *d* by getting into these circuits.

This work is performed at the factory before the cross-arms are carried out on the line. The earth wires projecting above the tops of the poles serve an excellent purpose as lightning arresters.

Fig. 173.

Great care is taken to keep the poles in a rigidly upright position, and in addition to placing them well in the ground and tamping the earth thoroughly around them, they are well supported with stays made of wire ropes attached to iron rods, which run into the ground about four feet. On straight lines and slight curves, where exposed to the wind, double stays are employed.

The insulators on the railway routes are uniformly of the Varley or double cone brown ware pattern (fig. 173), and those

upon the canals and highways of the single cone white ware, or porcelain. The Varley insulator is regarded as the best, but its greater cost has prevented its exclusive use.

It consists of two separate inverted cups, cemented together. The outer cup is provided with a groove to which the line wire is tied. A wrought iron bolt is cemented into the inner cup, by which the insulator is attached to the cross-arm. The bolt passes through the arm, as shown in the figure, and is fastened underneath with a nut.

Although the insulators employed upon the English lines are of the most approved form and material, they do not test exceptionally high, the resistance varying from 13,000,000 ohms per mile in moderately fine weather to 150,000 ohms in damp or very foggy weather. Wires of No. 4 gauge, 300 miles in length, work well with a mileage insulating resistance of 200,000 ohms; and those of 200 miles in length are worked when the insulation is less than 100,000 ohms per mile.

All the insulators used are carefully tested at the workshops of the department in Gloucester road before they are sent out. The insulators are placed in a wooden trough made in sections and lined with lead. Each section contains an insulator placed bottom upwards, the edges being covered with paraffin. The inside of the insulators and the trough are filled with acidulated water to within half an inch of the edge of the insulator. One pole of a 150 cell Daniell battery is connected to the lead lining of the trough, the other pole to one terminal of a very sensitive reflecting galvanometer—the other terminal of which is attached to a conductor with an insulating handle. The conductor is then inserted into the insulator; first into the interior and then into the crown, and if it is faulty in either part the needle will indicate it by moving.

The brown earthenware insulator is supplied by the manufacturer in separate pieces, and is put together at the works, the parts being tested separately. About two per cent. of the insulators furnished by the manufacturer are condemned by these tests and thrown out.

The conductors employed upon the English lines are composed of zinc coated iron wire of Nos. 4, 8 and 11 gauge. The No. 8 gauge—0.170 inch diameter—is the size in general use; the No. 4 gauge—0.240 inch diameter—being employed upon a few of the long circuits between the more important points; while the No. 11—0.125 inch diameter—is used for short lines only.

The method formerly followed of allowing the wires to pass freely through the insulators, and fastening them only at distances of half a mile, has been abandoned in favor of binding them at every pole, No. 16 charcoal wire being used for tie-wire.

Great care is observed in the jointing of the wires, which is invariably performed upon the line, no joints by the wire makers being permitted. The joint exclusively adopted is that known as the Britannia joint (fig. 174). This is made by slightly bending

Fig. 174.

the ends of the two wires and placing them side by side for a distance of three inches, binding them tightly together with No. 16 wire, and soldering them thoroughly. All joints are required to be soldered whether the wires be new or old, galvanized or plain. The leading-in wires at the offices are insulated with gutta percha, covered with linen tape, and varnished with a preparation made of linseed oil and Stockholm tar. These wires are re-tarred from time to time to prevent decay.

The over-house wires are erected in long spans, supported by iron poles attached to cast iron saddles, which are fitted to the ridge of the roof. The poles are light and well stayed by wire ropes. In London, cables containing fifty insulated wires are suspended by hooks from No. 8 iron wires, carried in the manner described above. The conductors in these cables consist of No. 22 copper wire.

At Newcastle on-Tyne a stand composed of seven steel wires, of No. 16 gauge and 454 yards long, is suspended over the Tyne, and supports a cable containing fifteen conductors. The cable rests upon ebonite chairs attached to the wire rope by means of rings placed at distances of twelve feet apart.

The over-house wires are used principally for lines which are leased by the Post-office Department to private firms or individuals for the transmission of messages on their own special business between offices, factories, &c., and which make a system of nearly 5,000 miles.

CONSTRUCTION OF LAND LINES ON THE CONTINENT.

The telegraphic system of Germany comprises some of the most thoroughly built and well designed examples of line construction to be found in Europe. The wood usually employed for poles is the pine (*pinus sylvestris*), although the oak is made use of to some extent. The poles are subjected to some preservative process before being used, the method usually employed being to impregnate them with creosote in a closed boiler. The minimum size allowed for poles is five and a half inches at the smaller end. They are cut in lengths of 21, 26 and 31 feet, and are usually set with about one fifth their length in the ground. The usual distance between the poles is 236 feet, or about 22 per English mile, but on curves they are placed nearer together. A system of A poles, similar to that described on page 310, is frequently made use of in carrying the wires around sharp curves and angles. Guy wires and stays are freely employed where circumstances render it advisable to strengthen the structure. Where a large number of wires are to be supported, double poles, similar to those described on page 310, are frequently made use of, the only difference being in the manner of arranging the insulators, which in Germany are supported on separate curved iron brackets instead of being placed on cross-arms, as in England. As usually arranged, the double poles referred to will carry 23 wires.

The insulator generally used on the German lines is a large

double bell of fine white porcelain, which is represented in section in fig. 175. These have been used since 1862 with excellent results, and for strength, durability, and high insulating qualities during rain, are probably unequalled by any other now in use in any part of the world. As will be seen by the figure, the outline of the insulator is a continuous curved line. This absence of abrupt corners adds greatly to the strength of the insulator, and diminishes its liability to become cracked or broken. The thickness of the porcelain is so great that the insulator is seldom injured by being struck by stones or other missiles. It is mounted either upon a straight iron bolt fixed upon the top of the pole, or upon a curved iron bracket, of the form shown in fig. 176, which is screwed into the side of the

Fig. 175.

Fig. 176.

pole. Where there are several wires, the brackets are placed alternately on opposite sides of the pole, so as to bring the wires about 18 inches apart. The form of the bracket is such that the strain of the wire comes almost exactly opposite the point where it is attached to the pole, and as the bracket is of inch square iron, the whole arrangement possesses great mechanical strength. The insulator is secured to the bracket by means of a packing of hemp saturated with linseed oil. The cost of these insulators in Berlin is 17 cents (gold) each, and of the iron brackets $7.70 (gold) per hundred.

The wire used on the principal lines is very nearly the same

as No. 5 Birmingham gauge. It is not galvanized, but is passed while red hot through a bath of linseed oil. This process gives it a varnish like coating, which prevents its oxidation for a long time. Galvanized wire was formerly employed, but it was found that in places where the wire was exposed to the injurious effects of smoke, acid, gases from chemical works, etc., that the galvanized wire became corroded even more rapidly than the oiled wire. Experience has also proved that in localities where the wires were not exposed to these injurious effects, the oiled wire has remained in good condition for more than 20 years. It has therefore been considered preferable, instead of using galvanized wire, to substitute an ungalvanized oiled wire of larger size, which can be obtained at the same price. This not only

Fig. 177

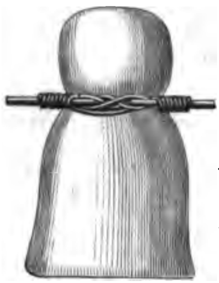


Fig. 178.

Fig. 179.

lasts as long or longer than the galvanized wire, but materially increases both the strength and conductivity of the line. The joints used are similar to those employed upon the American lines (page 289).

Fig. 177 shows the ordinary mode of tying the wire to the insulators, which is used on straight lines. The tie-wire is No. 14 or 16 annealed wire, and about 30 inches long. The drawing sufficiently explains the manner in which it is applied. Upon curves the wire is tied to the outside of the insulator in the manner shown in fig. 178. Still another arrangement is illustrated in fig. 179, which is adopted when the wire is to be allowed to reeve through the insulator, as in passing through a heavily timbered country.

The lines in the majority of the countries in Europe are constructed more or less upon the model of the German lines, except in Holland, where the English system seems to have been followed. The insulators used in France are, however, far inferior to the German model. Fig. 180 shows one of the kind most commonly employed. It is of a mushroom shape, and is mounted upon a curved iron bracket, which is fastened to the pole by lag screws. In some portions of Europe and Asia, especially where the lines run through uncivilized districts, in which the insulators are liable to injury, and where at the same time it is difficult to inspect or repair them at frequent intervals,

Fig. 180.

the iron-protected insulator, shown in fig. 181, is much used. It consists of a cast iron bell, which is provided on one side with a flange, by means of which it is screwed to the pole. An inverted cup of porcelain is cemented within, ribbed inside and out, to furnish a good hold to the cement by which it is fastened. The wire holder, or hook of iron, is again cemented into the porcelain cup. The several parts are put together while hot, with a cement composed of sulphur and oxide of iron. The insulating properties of this arrangement are not very high, but on account of its great mechanical strength it serves an excellent purpose practically under the circumstances above mentioned.

CONSTRUCTION OF LINES WITH IRON POLES.

As a general rule it is more economical to use wooden poles than iron ones, and therefore the employment of the latter has been confined to exceptional cases. It has been predicted that in time metallic poles will be employed exclusively for telegraph lines in consequence of their greater durability, the argument being that as an iron pole will last at least ten times as long as a wooden one, while its cost is not more than five times as great, the employment of iron must eventually result in a great saving. In calculating the relative economy of iron and wood, it must, however, be assumed that the difference of first cost in favor of

Fig. 181.

wood is to be placed at compound interest at the current rate, and it will therefore be seen that wood might possibly be the more economical in many cases, even if the iron pole is supposed to last for ever without deterioration in value. Compared with wooden poles, those of iron possess the advantage of greater permanence and elegance of form. From their uniformity the fittings are more readily applied or altered by unskilled laborers; they are also lighter and more portable, which are great advantages where transportation is expensive or difficult.

The iron poles which have been employed by the Swiss ad-

ministration since 1867, are of the pattern illustrated in fig. 182, and consist of a conical wrought iron tube, from 11 to 18½ feet in length, formed in a single piece. The diameter at the smaller end is an inch and a half. At the base the longer poles are 2.9 inches in diameter, and the shorter are correspondingly less. The thickness of the iron is uniformly one fifth of an inch. The foot of each pole is inserted into a block of stone, the dimensions of which depend upon the size of the pole it is intended to support. In fig. 182, which represents a pole eleven feet in length, arranged for 8 wires, the block of stone is two feet square. The iron brackets which support the insulators are placed one above another, alternately, on opposite sides of the poles, and are secured by means of keys or wedges of iron, in holes drilled transversely through the pole. The insulators are of glass, and are nearly identical in form with the flanged or umbrella pattern formerly so much used in the United States. The wires are 16 inches apart, and the lower one is only about 6 feet from the ground. The duration of these poles is, of course, almost unlimited, but a great objection to them is found in the small number of wires they are capable of accommodating in proportion to their cost.

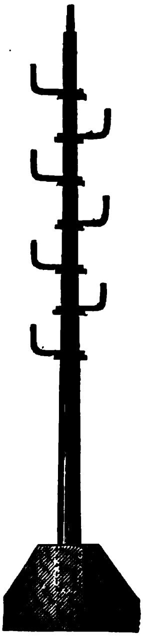


Fig. 182.

The Siemens iron pole has been used in many of the countries of Europe and Asia to a considerable extent, and this is especially true of the great Indo-European line, which extends from a point on the Russian frontier near Thorn, in Prussia, through Warsaw, Odessa and Tiflis, to Teheran, Persia, a distance of 2,850 English miles. The European portion of the line is constructed partly of wooden poles, but the poles throughout the Asiatic portion are uniformly of iron. The Siemens pole, fig. 183, is composed of two tubes, the upper one being set into the lower. A dish-shaped plate of iron is buried in the ground;

Fig. 183.

this is secured by four bolts to a hollow cast iron socket, 7 feet long and 4 inches in diameter, forming the lower section of the pole. This tubular socket is provided upon the inside, near the top, with a flange, upon which rests the upper portion of the pole of wrought iron, 13 feet long, with welded joints, and slightly conical in form. The total length of the whole, when put together, is 19 feet 8 inches, not including the lightning discharger, which projects 18 inches above the pole. When set up the pole stands 17 feet above the surface of the ground. These poles are made of different heights up to 24 feet, as required. The total weight of the ordinary sized pole is about 185 lbs. The figure shows the manner in which the insulators are attached to the poles. The ordinary number of poles used on the Indo-European line is 21 per mile, and these carry two No. 5 galvanized wires.

The Bavarian administration have within a few years commenced replacing the wooden poles in use in that country by a very substantial and elegant system of iron poles.

Fig. 184 represents the design which has been adopted by the Bavarian administration for iron poles. It consists of a rolled bar, the transverse section of which is of an **H** form, as in fig. 185, and is very similar to those used in this country for railroad iron. This form was selected as the one combining the maximum degree of rigidity with the minimum of weight. The principal strain upon telegraph poles is not in the direction of the wires which they support, but transversely. It is therefore apparent that the most suitable form for a pole is not one whose transverse section is cylindrical, but one which resembles an **H**, the web of the

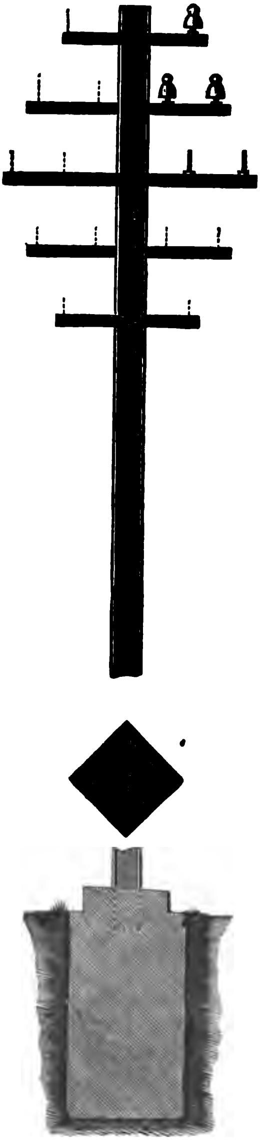


Fig. 184.

bar being placed at right angles to the strain of the wires. Poles of this form are not very costly, comparatively speaking, and but little trouble or expense is incurred in fitting the insulator and pins to them.

After being rolled, the poles are cut to the required length, and five holes, each about $\frac{5}{8}$ of an inch diameter and $15\frac{3}{4}$ inches apart, are drilled in the web of the pole for fastening the cross-arms. Opposite to these holes, and alternately upon opposite sides of the pole, recesses are cut out to admit the arms. The poles are washed with lime-water, and then plunged while wet into boiling oil, after which they are covered with a coat of red lead. The cross-arms are similar in section to an inverted L (see fig. 186), and are of three different lengths, viz: 2 ft. 7 in., 3 ft. 6 in., and 4 ft. 7 in. A $\frac{5}{8}$ inch hole is drilled midway of the length of each arm, to receive the bolt which secures it to the pole, and a suitable number of $\frac{5}{8}$ inch holes are drilled in the upper flange, to receive the insulator pins or bolts. The cross-arms are attached to the poles by $\frac{5}{8}$ inch bolts $2\frac{3}{4}$ inches in length, secured by hexagonal nuts. The insulator pins are of iron, 8 inches long and $\frac{5}{8}$ inch maximum diameter, fastened to the cross-arm by a nut underneath the flange, as shown in fig. 186.

The stone blocks at the foot of the pole are of fine grained granite, 4 feet 2 inches in height and 18 inches square. A hole of the same form as the transverse section of the pole, and 10 inches deep, is drilled in the vertical axis of the granite block, and only large enough to allow the pole to enter. Melted lead is then poured into the intervening space, until it runs over and forms a pyramid around the base of the pole, entirely covering the opening of the stone.

After the poles and cross-arms are in place, they are covered with a thick coating of gray zinc paint. To guard against the splitting of the granite sockets by lightning, each pole is provided with a ground wire of No. 9 iron, one end of which is

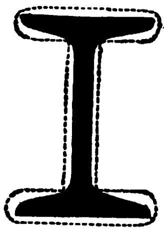


Fig. 185.

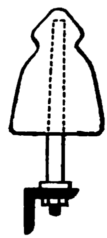


Fig. 186.

buried in the earth and the other embedded in the mass of melted lead at the base of the pole.

Along the railroads the poles mostly in use are those of about 16 feet in length, but at level crossings the length is increased to 23 feet. On straight lines and in a level country about 36 poles to the mile are used. Such a line of poles will carry 16 No. 7 wires without difficulty.

This method of constructing lines has given entire satisfaction. The interference between different wires is entirely overcome by the use of the iron poles, which in this respect seem to act somewhat like condensers. The cost of the poles, including painting, fitting, and everything except insulators, is about $14 (gold) each.

CHAPTER XXIV.

THE PHENOMENA OF CHARGE AND DISCHARGE ON LAND LINES.

If we connect one end of a telegraph line with one pole of a battery, and place the other pole of the battery and the other end of the line in connection with the earth, the current pervades the entire line almost instantaneously, reaching the farther end of the line at nearly the same moment that contact is made with the battery. Upon the first appearance of the current at the extreme end of the line, however, it is exceedingly weak, but it constantly increases in strength until it reaches a maximum, which it maintains without further change so long as the connection with the battery continues, and the line is perfectly insulated. If we insert a galvanometer at the distant end of the line, the latter shows no deflection until the current becomes sufficiently strong to influence the needle. The more sensitive the galvanometer is, the sooner it will be affected by the current, and the shorter also will be the time that will elapse between the making of the contact with the battery and the perceptible appearance of the current at the distant end. The deflection of the needle continually increases as the strength of current augments, but does not become constant until the current has attained its maximum, which requires a perceptible though very brief interval of time. If we insert several galvanometers at different points upon a long line, and make contact with the battery, the needle of the galvanometer which is nearest the battery will first be deflected, a moment later the second follows, then the third, and finally the one most distant from the battery. In the case of all the galvanometers that are on the half of the line nearest the battery, the angle of deflection increases very rapidly, passing at first beyond the point at which the needle finally settles, and then again decreasing to that point. It is

quite otherwise with the galvanometers that are placed on the second half of the line; their movements, which are feeble at first, continually increase until after a certain time has elapsed, when the galvanometers at the various points all show the same deflection, which continues permanently if the insulation of the line remains constant.

The condition of the line during the time that the strength of current is constantly increasing—that is, from the moment that the line is connected with the battery until the strength of current in all parts of the line is the same—is called the variable state, to distinguish it from the permanent state, in which no change of this kind occurs. The permanent state is first attained in the middle of the line, and takes place there four times sooner than at either end.

The time which it takes the current to make itself manifest upon the galvanometer depends upon the sensitiveness of the latter, consequently, neither the instant when the first portion of the current reaches the end of the line, nor the moment when the current begins to be constant, can be exactly determined. Of two galvanometers, the one which is most sensitive is first to show the passage of a current. In consequence of this the duration of the variable condition cannot be stated with absolute exactness, and we are obliged to confine ourselves to the determination of the time which is required for the current to reach a state that approximates closely to the permanent state.

DURATION OF THE VARIABLE STATE.

If we assume with Ohm that electricity flows through a wire in accordance with the same laws that govern the diffusion of heat in a rod which is heated at one end, we are led to the conclusion that the duration of the variable state is in proportion to the square of the length of the line. If, for instance, a certain line is 2, 3, 4 or more times as long as another, then the duration of the variable state is 4, 9, 16, etc., times as long as in the case of the shorter line. Gaugain and Guillemin have experimentally proved the accuracy of this law. The duration of the

variable state depends also upon the conductivity, the sectional area, and the degree of insulation of the line, and upon the quantity of electricity which is required to produce a certain potential through the unit length of line. With ordinary iron telegraph wire of No. 8 gauge the duration for a length of 300 miles varies, according to atmospheric conditions, between .014 and .022 seconds; on an average it may be said to be about .018 seconds. In accordance with the preceding law the time t of the variable period for a line of 500 miles would then be given by the proportion

$$t_1 : .018 = 1 : (300^2)$$

or

$$t_1 = .000000162 \text{ second.}$$

We shall hereafter see what influence the other circumstances above mentioned have upon the duration of the variable period.

CHARGE OF AN INSULATED LAND LINE.

Ohm's laws give no sufficient explanation concerning the manner in which electricity diffuses itself under some conditions. Many phenomena appear upon long telegraph lines which are not observable upon short ones, and which are entirely distinct from the phenomena of the ordinary galvanic current.

Wheatstone, Guillemin, and especially Gaugain, have very carefully studied the manner in which electricity from a battery is propagated through a long conductor, and we shall therefore state briefly some of the more important results of these examinations.

If, by turning the switch k on 1 (fig. 187), a wire completely insulated throughout is put in connection with one pole of a battery, the other pole being to earth at E, we shall find that the galvanometer G interposed between the wire and the battery indicates a current the moment that the switch is turned on 1. This current, which is powerful in proportion to the length of the line, originates therefore without the existence of a closed circuit, but its full strength lasts only for a very small portion of a second. After the first and almost instantaneous deflection, the needle of the galvanometer again returns to its

state of rest, or at most only shows a very small deflection in consequence of the line L not being perfectly insulated.

As soon as the line wire L is connected to the pole of the battery it becomes electrified, and attains throughout its entire length the same potential that the pole of the battery itself possesses; consequently, as the current passes into the wire it manifests its presence first in the neighborhood of the battery. This effect, however, ceases as soon as the charge reaches the extreme end *b* of the line, and the line itself attains at all points the same potential as the battery pole. The earth E with which the other pole of the battery is connected, may be replaced by any other conductor having the same capacity as the line L.

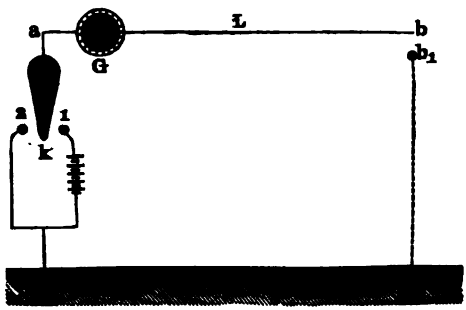


Fig. 187.

Although the electrical potential of the battery pole and of the separate parts of the line may not be very high, yet the amount of electricity which flows into the wire may be considerable, as a long line has, in the aggregate, a very large surface; consequently, a considerable amount of electricity, when distributed over the entire surface, would present at any given point of it only an inconsiderable density, and consequently a low potential. A No. 8 wire, such as is ordinarily used for telegraph lines, has a surface of 228.04 square feet per mile, and a No. 6 wire 280 37 square feet per mile, which would give for a line of 500 miles the enormous surface 140,185 square feet.

When the wire L has attained an equal potential at all points, in consequence of having been connected with the pole of the

battery, the wire is said to be statically charged, and the operation is termed charging the wire.

The charge resides only upon the surface of the line wire, and its amount is determined both by the magnitude and form of this surface. It is proportional to the length of the line when the latter is so well insulated that all its parts attain the same potential; it increases also with the volume of the conductor, and is in exact proportion to the electro-motive force of the battery.

DISCHARGE OF INSULATED LAND LINES.

If we insulate a charged conductor L (fig. 187) by removing the switch *k* from 1 and placing it between 1 and 2, thus breaking connection with the battery, its electrical condition will remain unaltered, provided the insulation is perfect. As this is never actually the case in practice, the charge of the line passes off at the points of support and at such other points as derivations may occur. The more defective the insulation is the sooner will the charge become dissipated.

This flow of electricity from a charged wire takes place with exceeding rapidity on air lines. Even with the best insulated ones it rarely occupies more than a very small fraction of a second. The case is quite different with underground or submarine lines, in which the wire is carefully covered with insulating substances. A tolerably well insulated cable will, under these circumstances, retain its charge so well that, even after a lapse of twenty or thirty minutes, it will only have lost half of the electricity which it received when being charged.

When, however, after having charged the wire L, we separate it from the battery, and then, before any considerable loss of electricity occurs, connect the same end of the wire *a* to the earth E, the electricity which at first flowed in suddenly flows out of the line again, and the inserted galvanometer G marks the passage of a momentary current whose direction is opposite to that of the charging current. This may be accomplished in the simplest way by quickly turning the switch *k* on 2, after

having placed it on 1 to charge the wire. By this means the end *a* of the wire is separated from the battery and placed in connection with the earth. This second current flowing from the line to the earth is called the discharge or return current.

If, instead of the end *a*, we had connected the end *b* of the line to earth, then the discharge current would have taken place in the direction *a* to *b*, and the deflection of the needle of a galvanometer inserted at *b* would have been in a direction opposite to that of the preceding one.

When the line is discharged, the galvanometer needle is also deflected to a certain maximum, and then, after several oscillations, finally returns again to its state of rest. As the deflective force of the return current acts on the needle in these cases almost instantaneously, the mode of its action upon the needle is similar to that of a blow against a pendulum; that is to say, the deflective force, or the magnitude of the discharge, is, in accordance with physical laws, proportional to the sine of half the angle of deflection, and is entirely independent of the kind of galvanometer used.

It is evident that the same law also holds good for the charge; consequently, if we indicate the magnitude of the charge by A, that of the discharge by B, and corresponding angles of deflection by α and β respectively, using the same galvanometer for the two deflections, then,

$$A : B = \sin. \frac{\alpha}{2} : \sin. \frac{\beta}{2}$$

As the electricity with which the wire is charged becomes gradually dissipated after the charge has been effected, either through the air or by means of other partial conductors, the return current becomes proportionately weaker as a greater length of time elapses between the charging and discharging. If the line were perfectly insulated, and there was, therefore, no escape of the electricity, or if the discharge could be made to take place simultaneously with the interruption of the battery, the discharge current would be just as strong as the charge current; but as this can in reality never occur, and as some time always

elapses between the operations, the discharge current is necessarily always less than the charge current.

The more perfectly a line is insulated the less will be the loss of the electricity with which it is charged in a given time; consequently, the proportion between the quantity lost and the primitive charge may be made to serve as a means of determining the condition of the insulation.

If we retain the same indications for quantity of charge and discharge as before, and assume that the discharge takes place half a second after the charge, then the line in this space of time loses a quantity of electricity A—B. The proportion between this loss, caused by derivations or leakages, or, in general, by defective insulation, and the primitive charge, amounts, therefore, for half a second, to A—B. The smaller this proportion the better is the insulation of the line.

On air lines of 5 to 10 miles in length these currents are not perceptible even when using a battery of 300 elements, but with a length of 20 miles both currents are easily rendered apparent by using a powerful battery and a very sensitive galvanometer; when the length exceeds 100 miles even the relay magnets of the telegraph apparatus will show them.

In what has been said it must be borne in mind that the end *b* of the line L (fig. 187) is insulated, while the charging or discharging is done at the end *a*.

CHARGING AND DISCHARGING A LAND LINE CONNECTED TO EARTH.

If we put the end *b* of a land line L (fig. 187) to earth by connecting *b* with b_1 and earth plate with E_1, a constant current, as we know, traverses the line as soon as the battery is connected. This current is indicated by a permanent deflection of the galvanometer needle, and lasts as long as the battery remains in circuit. In this case the electric potential at each point of the line is not equally great, but decreases continually throughout from the pole 1 to the extreme end b_1 and E_1. Owing to this decrease of potential from point to point, a con-

stant flow of electricity from the battery through the line to the earth E takes place. If the potential at *b* is the same as at 1 and at *a*, then there will be no flow of electricity from 1 to *a* and *b*. The wire L becomes, even in this case, charged with electricity, but the amount of the charge is smaller than when the end *b* is insulated, while in the latter case the potential is the same at all points.

Blavier very properly compares both the charging and discharging of a line, when the distant end is insulated and uninsulated, to the movement of a gas through a tube, one of the ends of which communicates with a large reservoir, in which the gas is under a constant pressure, the other end being placed in a vacuum.

If we interrupt the connection with the vacuum and close the opening of the tube at this end, the gas flows into the tube only so long as the pressure is not the same at all points.

This is precisely the case with a telegraph line when one end is insulated. The reservoir represents the battery, the tube the wire, and the gas the electricity.*

When, on the contrary, the end of the tube is placed in the vacuum, and the gas is allowed to flow through it, then the pressure in the immediate neighborhood of the reservoir is equal to the pressure of the gas in the reservoir itself, and it decreases gradually to the end of the tube, where it becomes zero. Consequently the total amount of gas in such a tube is less than in the former case, when the tube is closed at the end.

We may obtain a good idea of the condition of the static charge in a line insulated at the remote end, and of one having that end connected to earth, if we suppose the potential of the separate points to be represented by vertical lines which are erected at the respective points.

Let AB (fig. 188) be the length of the line; suppose it to be

* The comparison, however, is not exact, since in charging the wire with electricity we need not suppose a real propagation of the electrical fluid from one point to another, but should rather consider it to be the result of a progressive decomposition and recomposition of the natural electricity.

connected to one pole of the battery at A, and let the potential on this pole be represented by the vertical line AC erected at AB. If the extreme end B of the line is now insulated, by which the potential at all points of the line becomes equal to AC, then the vertical lines GH, EF, IK, BD, which are each equal to AC, represent the potential at the points A, G, E, I, B. The total charge of the line is, therefore, the sum of all the perpendiculars of the length AC, which it is possible to conceive of as existing between A and B; that is to say, it is proportional to the contents of the rectangle ACDB.

When, on the contrary, the end B is connected to earth, then the electric potential from A towards B decreases in proportion to the distances taken, if we still represent it at A by AC, then for the distances AG $= \frac{1}{4}$ AB, AE $= \frac{1}{2}$ AB, AI $= \frac{3}{4}$ AB, it

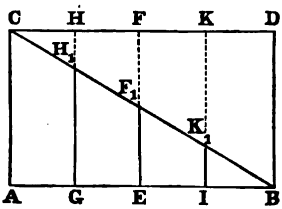


Fig. 188.

will be respectively $\frac{1}{4}$ AC, $\frac{1}{2}$ AC, $\frac{3}{4}$ AC, and at the point B it falls to zero. Consequently, if we draw the line CB, the verticals GH_1, EF_1, IK_1, will represent the charges corresponding to the points G, E, I. The total charge of the line AB is, therefore, equal to the sum of all the verticals included between AB and CB. Consequently, it is proportional to the area of the triangle ACB.

It follows, then, that the total charge of a line whose distant end is connected to the earth, is only half as great as when the line is completely insulated.

RETURN CURRENT IN LAND LINES WHEN PUT TO EARTH.

When the line L (fig. 189) is in contact with earth E_1 at the point *b*, and the switch *k* is turned on 1, then L receives a charge

half as great as if b were insulated. If now the connection between the line and battery is broken, the electricity which is distributed on the line rapidly escapes through b to the earth E_1. For this reason, the duration of the discharge for ordinary land lines is exceedingly short—at any rate, very much shorter than when the line is insulated at b—in which case the discharge can only be effected through the air and by the poles, so long as k remains between 1 and 2.

When, however, the line is very long, for instance 100 miles or more, the discharge does not take place in an immeasurably short period of time.

If we turn the switch very quickly from its position 1 to 2, then the discharge takes place in two opposite directions; the

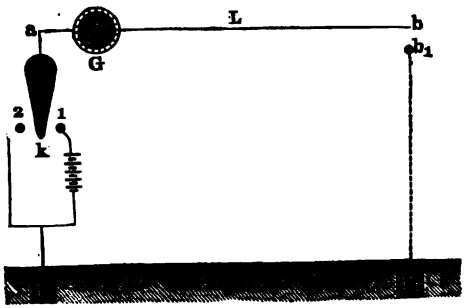


Fig. 189.

greater part of the charge in the vicinity of the battery passes over k and 2 to earth E, producing the return current, whose direction is opposite to the direction of the charge; the other and smaller part flows in the direction of the charge (from a to b) through b to earth E_1. The return current may be observed on a sensitive galvanometer, G.

The discharge may also be delayed and made apparent on a line without insulating its end b, by inserting a considerable resistance between b and the earth E_1.

As this opposes to a considerable extent the flow of electricity at b, the return current at a will be much stronger when the switch k is quickly turned from 1 to 2.

The same effect takes place when, instead of an artificial resistance at *b*, a considerable resistance is accidentally present in the line itself, such for instance as may occur in consequence of defective wire connections or bad connections in the instruments. This fact often enables us to form a conclusion, from the appearance of the return current, whether there is a defect at the other end of the line.

We must not, however, confound the return current with the so-called extra current, which originates at the moment the battery is placed in circuit, and also opposes the main current; this extra current occurs only at the moment that the battery is closed, while the extra current, which appears at the interruption of the battery, has the same direction as the main current in the line.

On breaking battery connection by turning the switch *k* (fig. 189) from 1 to 2 quickly, there results, especially in very dry weather and upon long lines, say of at least 250 miles in length, an extra current as well as a return current. These are, however of opposite direction; the return current being opposite to that of the battery current, while the extra current (opening) is in the same direction as the battery current. By means of a very sensitive galvanometer we may therefore determine which of the two is the strongest.

On very short lines, the extra current which appears when the battery is interrupted, and whose direction is the same as the line current, is the most powerful; that is to say, the extra current is more powerful the shorter the line is, while the return current may not be perceptible at all.

If the length of the line is increased and the battery suddenly disconnected, by turning the switch *k* from 1 to 2, the return current makes its appearance, and is distinguished from the extra current by its direction. It increases, also, in the same proportion that the length of the line is increased.

Both currents may be recognized when the battery is suddenly interrupted and the line connected to the ground, with the ordinary Morse duplex apparatus, by the attraction of the armature

levers. With the step-by-step printing instruments, both currents are perceived when the line is more than 100 miles long and the transmitter makes from 10 to 12 pulsations per second.

ESCAPES AND LEAKAGES OF CURRENT UPON LAND LINES.

Telegraph lines suspended from insulating supports are necessarily in contact with these supports and with the atmosphere. When the insulation is defective, or the air heavily loaded with moisture, a considerable portion of the electricity which is supplied to the line by the battery escapes from thence, and finds its way into the earth and into the surrounding atmosphere. The conductivity of the atmosphere depends upon the amount of moisture contained in it, but in any case it is so small in comparison to that of the insulators and poles as to be scarcely perceptible under the most unfavorable conditions. During dry weather the shape of the insulators has but little influence upon the amount of electricity which escapes from the line to the earth; when, however, the weather is damp, foggy or rainy, the insulators and poles become covered with a conducting film of moisture, and under these circumstances the shape of the insulators has a very material effect upon the loss of current which takes place. In addition to this, dust, smoke, and other impurities collect more or less upon the surfaces of the insulators as well as the poles themselves, especially in the vicinity of manufactories or other localities where bituminous coal is burnt, and thus a conducting connection is formed with the earth, which occasions very serious escapes or losses of current As the number of these points of escape increases in direct proportion to the number of supports, it is obvious that the insulation of a land line is increased by diminishing the number of poles.

As an approximate estimate it may safely be assumed that during the prevalence of continued unfavorable weather, such as rain or fog, that the resistance offered by the points of escape will not exceed 300,000 to 500,000 ohms upon each mile of the length of line, and if we assume that there are 30 insulators to the mile, then each insulator forms a conductor to the earth,

the resistance of which is from 9,000,000 to 15,000,000 ohms. The loss at each insulator is therefore equal to the strength of current in a line of No. 8 wire from 600,000 to 1,000,000 miles in length. This is technically termed the insulation resistance, as distinguished from the conductivity resistance, or that of the conductor itself without reference to the insulation. These terms are, perhaps, not the best that might have been chosen, but they are nevertheless in general use.

The resistance of the insulators often changes very rapidly on the same line; for instance, when the sun shines out, after a shower of rain or a dense fog, the outer surface of the insulators quickly becomes dry, and the insulation of the line therefore increases with great rapidity. It reaches its maximum during the warmest weather in summer, and especially during the intense dry cold of a northern winter.

When a telegraph line is connected to the earth at both ends, only a portion of the current entering the line from the battery reaches the distant end, and the more defective the insulation the smaller will be the fraction of the entering current which is received at the distant end. On a line of 300 miles the arriving current, when the weather is unfavorable, frequently amounts to not more than one fourth or one fifth of that leaving the battery. When the insulation is good, the arriving current on a line of the above length amounts to three fourths or more of the entering current.

In order to compensate for the loss of current which arises from these escapes, it is necessary to make use of a battery of a larger number of elements than would otherwise be required. There is, however, a limit to the number of elements that can be used in any particular case, and thus there must also be a limit to the distance which a telegraph line can be successfully operated in a single circuit. This limit depends upon the strength of the battery used, the relative resistance of the conductor and of the insulators, and the sensitiveness of the instruments used. With the apparatus now in use in this country it is customary to allow one cell of gravity battery to every 40 or 50 ohms of resistance in the circuit.

CHAPTER XXV.

UNDERGROUND OR SUBTERRANEAN LINES.

THE many dangers and interruptions to which land lines are subject, the rapid deterioration of telegraphic structures when exposed to the weather, and more especially the interferences and difficulties which are unavoidable when a number of wires are carried through the limited space afforded by the crowded streets of large cities, have led telegraphic engineers to seek relief from these manifold interruptions and annoyances by enveloping the conducting wires in some suitable insulating covering, and burying them beneath the surface of the earth. Such a mode of construction, if not open to fatal objections in other respects, would obviously present some important advantages. The lines would be comparatively free from interruptions, arising either from storms, atmospheric electricity, or intentional injury.

The first recorded attempt to construct an underground telegraph line was made by Prof. Jacobi at St. Petersburg, Russia. The conducting wires were enclosed in glass tubes, the ends of which were cemented together. The results obtained were not very satisfactory, nor did a subsequent attempt to insulate the wires, by means of ribbons of india rubber wound around them, meet with any better success. The earliest experimental telegraph lines, both in Great Britain, in 1839, and in the United States, in 1843, were composed of copper wires covered with cotton or hemp, and varnished with insulating substances, which were laid underground in iron or leaden tubes, to protect them both from moisture and accidental mechanical injury. This method also proved entirely unsuccessful in practice.

The first extensive system of underground lines was laid in

Prussia. A royal commission was appointed in 1845 or 1846 to consider the subject of a telegraphic system, of which Dr. Werner Siemens was the most active member. In 1846 gutta percha first began to attract attention in England, and Mr. C. W. Siemens sent a sample to his brother at Berlin, to see whether he could use it for the purpose he had in view. Dr. Siemens soon discovered its remarkable insulating properties, and recommended an experiment on a large scale, which, having been sanctioned by the Government, he completed an underground line of four or five English miles, between Berlin and Gros-Beeren, in the summer of 1847. This having been found to answer the purpose, in the same and following years more than 3,000 miles of gutta percha coated line wire was laid down underground, and proved successful for several years, when it began to fail, and at length was wholly abandoned, and replaced with lines erected upon poles.

The first telegraph line ever built in the United States, between Washington and Baltimore, by Professor Morse, was intended to have been laid underground. Four No. 16 copper wires, covered with cotton and shellac, were drawn into lead pipes, and ten miles of such cable were laid down from Baltimore to the Relay House, in December, 1843. The experiment proved a total failure, and the wires were then taken out of the tubes and placed on poles. Ten or twelve miles of wire were also laid underground, on the line between Martha's Vineyard and Nantucket, in Massachusetts, in 1856. This worked very well for two or three years, but the insulation, which was of gutta percha, soon failed, and the line was abandoned. There are now no underground lines in operation in this country.

In 1853 the Magnetic Company of England completed a line between London and Manchester, consisting of ten wires laid in grooved boarding, the wires being of No. 16 copper, insulated with gutta percha to No. 3 gauge. The wires were placed parallel to each other, in two rows, and were served over with two coverings of jute soaked in Stockholm tar.

The boarding used was creosoted Baltic timber, 3½ inches

square, and was placed at the bottom of a trench two feet deep. The cable was coiled in lengths of about $1\frac{1}{2}$ miles on a drum placed on wheels, and was drawn over the ground by a horse. When a convenient length was paid out along the road, it was lifted up and placed in the boarding, which was then covered by a wooden top and nailed on. Where iron piping was required split pipes were used. At the end of every mile and a half, and also where it was required to make a set of joints, test boxes were inserted, two feet long by three inches deep, at the same level as the board. Where boarding was used these boxes were wooden, and iron where the piping was iron.

The tests of the wires were taken both for continuity and insulation. All the wires were marked at their ends with lead numbers.

Before the work was finished a great number of faults were found, generally due to nailing on the cover, the nails frequently being driven into the gutta percha. A long length of line had all its nails renewed, and the boarding bound with wire. A few years after the completion of the work the wires continually failed, and when a fault was located in any wire the cable was opened and a good wire substituted for the faulty one. Subsequently the line was tested in five mile sections, and when any section was found defective it was replaced by an overhead line, and the underground cable removed. This course gradually resulted in the replacement of the line by an overhead one, until at length none of the original work was left. The faults which appear to have caused the abandonment of the gutta percha cables were the drying up and cracking of the gutta percha in sandy ground; the rotting of the gutta percha in dirty, stagnant water; the formation of fungi on the gutta percha near oak trees; the destruction of the gutta percha by gas water near gas pipes; the burning of the gutta percha by the carelessness of the workmen engaged in laying it; the rotting of the gutta percha under the lead numbers, and the pricking of the wires and omitting to seal the places up.

The underground lines in the Isle of Wight consisted of bare

india rubber wires, put down without any protection whatever. The wires were abandoned a few years afterwards.

In 1852 the Electric and International Company laid down eight wires, insulated with gutta percha, between London, Liverpool and Manchester. The wires were laid in earthenware pipes. The line was broken up in 1862, and the old materials sold for enough to build an overhead line to replace it.

Comparatively few underground lines are now employed, except in carrying the lines through the streets of some of the principal cities of Europe, from the central telegraph office to the different railway stations, from which they are placed on poles set alongside the railways. The English telegraphic engineers have probably devoted more attention to the construction of underground lines than those of any other country, and, as might be supposed, their efforts have been attended with better practical success. For this reason we shall proceed to describe in detail the most approved methods of construction which have been adopted in England.

UNDERGROUND LINES IN ENGLAND.

The present system of underground lines in England is quite extensive, embracing as it does 3,000 miles of wire and nearly 100 miles of iron piping.

The conductors usually employed for these lines consist of No. 18 copper wire, covered with gutta percha to the gauge of No. 7. In order to keep the gutta percha from the atmosphere, an exposure to which would cause it to crack and decay and thus destroy the insulation, it is first tarred and then covered with linen tape and tarred again. The preparation of tar through which the gutta percha and taped wire is drawn is composed of one quart of raw linseed oil to two gallons of Stockholm tar, and is applied warm.

The wires, when thus prepared, are cut into lengths of four hundred yards, and as many as are required to be laid in one tube are made into a loose cable, and tied together with tape at distances of six feet apart. When the wires are drawn into the

tubes the tapes are removed and the wires permitted to lie loosely in the pipes.

The tubes into which the wires are drawn are cast iron socket pipes of two, three, and four inches diameter—the size employed depending upon the number of wires to be laid down. The two-inch pipe will accommodate 25 wires; the three-inch, 70 wires; and the four-inch, 120 wires. The pipes are laid down under the flag stones at an average depth of twenty inches, and the joints are filled with lead.

Oblong drawing-in, or flush boxes, made of cast iron, thirty inches long by eleven inches wide and twelve deep, with lids formed of an iron frame into which a piece of flag stone is fixed, are also placed under the sidewalk over the curbing, at distances of fifty yards, in the City of London, and one hundred yards apart outside the city. The pipes enter these boxes through a curved aperture near the bottom, which is open.

As the pipes are laid down an iron wire of No. 8 gauge is strung through them to draw the cable in with. When the wires are to be laid down they are tied into loose cables, as above described, in lengths of 400 yards each, and brought to the middle of a section of 400 yards of tubing. One end of the cable is then attached at the flush box to the iron wire extending through the pipe in one direction, and the other end of the cable to a similar wire extending through the pipe in the opposite direction. The cable is then drawn through both sections at the same time—a distance of 400 yards—the greatest distance that any part of the cable has to be drawn in the tube being 200 yards.

The wires are numbered at each 400 yards, and the boxes are arranged so that the joints and numbers are always in the box. The wires may be replaced in the pipes for repairs or other purposes at any time without interrupting communication or disturbing the pipes. When a section is found to be defective and to require renewal, a cable of wires of the required length is brought to a box near the defective wire and inserted in a loop between it and the next section, and as the defective piece

is drawn out of the pipe the new piece is drawn in. Extra wires are always provided when new wires are drawn in, so that renewal is not required until several wires have failed. It is impossible to draw out a portion of the wires without injuring the coating and thereby destroying the insulation. Hence, when renewal becomes necessary, all the wires in the section are replaced. The pipes are well cleaned and tarred inside while hot, in order to prevent rust, which causes the wires to adhere so strongly to the iron as to become difficult to detach them.

The cost of laying down three inch cast iron socket pipe for underground wires is three shillings and ninepence per yard, or £330 per mile. This includes the cost of the pipe and jointing with lead, the taking up of the pavement, putting the pipe in place and repaving.

The cost per wire for drawing in the pipes depends somewhat upon the number of wires. The average cost of putting sixty wires in a pipe, including jointing and all other incidental work, is £56 per mile.

The cost of conducting wire for underground lines, consisting of copper wire of No. 18 gauge, covered with gutta percha to No. 7 gauge, taped and tarred, is £17 per mile.

The total cost per mile for sixty underground wires is £1,406, or £23 8s. 7d. per mile of wire.

The underground system in England gives comparatively little trouble, and is more favorably regarded for carrying the wires through large cities than the over-house plan, the great defect in which is imperfect insulation.

For tunnels, copper wires, insulated with gutta percha, and then tarred, taped and again tarred, are laid in a wooden trough and attached to the wall. The trough has a cover, coated with zinc, and fastened with tie wire instead of nails, to prevent injury to the wires.

Since the telegraphs have gone into the hands of the Government a new underground line has been laid down between Liverpool and Manchester, consisting of fourteen conductors, laid in iron and stoneware pipes. The length of the line is about

36 miles, and about two thirds is laid down in stoneware pipes and one third in iron pipes.

The iron pipes are three inch cast iron in nine feet lengths, with sockets for joints. The stoneware pipes are three inches in diameter and three feet in length. The depths at which the pipes are laid are one foot for the iron and two feet for the stoneware. The iron pipes, previous to laying down, were cleaned out with a heavy iron chain, for the removal of any sharp points and burrs. The stoneware pipes were cleaned with a rod with two pieces of iron, like half pipes, kept apart by a spring.

The pipes when laid down were carefully adjusted, so as to fit closely, and the joints were then made. As each pipe was laid in its place a No. 16 galvanized iron wire was threaded through.

The joints in the iron pipes were made by first ramming in some yarn, to prevent the molten lead from running into the pipe. A clay mould was then formed around the pipe and the lead run in. The quantity of lead used for this purpose was about one pound per joint.

In the stoneware pipes the joints were made with Stourbridge clay, which, whilst making a good joint for the prevention of dirt entering the pipe, is sufficiently porous to allow water to percolate through it.

At the distance of every 200 yards, in straight lines, were placed flush-boxes, into which the pipes were led so as to just project within, the space around them being protected, so as to prevent dirt from falling into the box. The mouth of each pipe was also stopped, to prevent dirt from getting into the pipe.

The cables were divided into 403 and 404 yards lengths, and the whole work was subdivided into 400 yard lengths—the boxes at these intervals being termed joint boxes, and the intermediate drawing-in boxes. The joint boxes were placed at the distance of 400 yards apart. The intermediate or drawing-in boxes, in a straight line, were placed at 200 yards from a joint box, or half way between the joint boxes, but where there were

curves in the road, or it became necessary to make a cross, these intermediate boxes were increased as the occasion required.

The cables used in this work consisted of a copper wire of No. 18 gauge (39 lbs. per mile), covered with gutta percha to No. 7 gauge (46 lbs. per mile), and were manufactured in the ordinary way—being covered with two coats of Chatterton's compound, alternating with two of gutta percha, and having a total weight of 85 lbs. per mile.

The core, as it was manufactured, was cut off into special lengths for the length of cable required—404 yards. The wires so cut off were wound on to bobbins, which were placed in a machine holding six bobbins only. The bobbin containing the centre wire was placed behind the machine, through the centre of which the wire passed—the six wires being laid helically round the centre. The cable was then passed through a bath of cold Stockholm tar, in which was a quantity of fine cork dust, to give it more solidity, and was then covered with two servings of tarred tape laid on in opposite directions, the tape having a double selvage.

The several holes where boxes were located having been opened and the boxes cleaned out, two strong drawing-in wires of No. 11 gauge were attached to the No. 16 wire left in the pipes; this was then drawn out and the No. 11 wires drawn in for the entire length. To the end of this wire, in which a loop had been formed, were attached the several cables, the attachment being made by stripping the gutta percha off the copper of each wire for some inches, care being taken to keep all the wires of the same length. The copper wires were then passed through the loop, bent back, twisted and secured. The whole of the ends were lapped over with tape and yarn to prevent abrasion. Before the wires were cut the numbers were put on. As the cables were made of six wires laid helically round the inner wire, it will be obvious that the wires, if numbered properly, would follow in succession. All the wires in the cables had been numbered and stamped at both ends from 1 to 6 on the outside—the centre wire, No. 7, not being marked, so before the wires were

cut, numbers marked on short pieces of lead tubing were slipped on the wires, care being taken that the numbers corresponded with the numbers stamped on the gutta percha.

The cables, when ready for drawing in, were placed upon drums or swifts revolving on a stout frame, and at a convenient distance from the mouth of the pipe to avoid friction against the various points. Close to the mouth of the pipe was placed a

Fig. 190.

wooden roller so as to prevent any friction against the edges of the pipe. At the opposite end of the box was placed a mat for the cables to touch instead of the ground, in order that no dirt might be carried in. Drawing in cables in a straight length is begun at the centre box, and the cable is first drawn through to B and then to C (fig. 190). In cases where there are two intermediate boxes, the drawing in is done once oftener. The cables

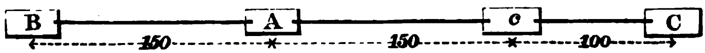


Fig. 191.

are first drawn in from A to B, then the remainder from A to *c*, and finally from *c* to C (fig. 191).

In the case of a still larger number of boxes, the drawing in has to be done still oftener. One half of the cables are drawn through from A to *b*, and then from *b* to B, the other half being drawn through from A to *c*, and then from *c* to C (fig. 192).

When a break occurred in drawing in the cables, the wire was

Fig. 192.

drawn out and laid along the trench to measure the distance of the break; the trench was then opened, a pipe broken, and a wire threaded through the hauling-in box; or, if the length was too great, a wire was threaded from the break and also from the box by looping the ends, and when sufficiently far through

the wire was given a circular or twisting motion, when the looped or forked ends were almost sure to catch. The wires were then drawn out and attached to the broken wire of the cable.

After the cables had been drawn through one section of the pipes they have to be drawn into the opposite end, and to do this it is necessary to turn them over so as to bring the ends uppermost. The cables as they come out of the pipes are protected by a roller from any friction against the edge of the pipe, and then carefully coiled on to a sheet of canvas. They are then, preparatory to drawing in again, turned over by being coiled down on to the opposite side of the box on to canvas.

In the case of several intermediate boxes and a large number of wires, the drawing in the wires, and the drawing in and out, and the coiling and uncoiling of the cables, occupies a great length of time, which is much increased in the towns by the interference caused by traffic.

GUTTA PERCHA JOINTING.

Of the various operations connected with practical telegraphy, there is scarcely one of more importance, or requiring more practice, skill and experience, than the making of a joint in a gutta percha covered wire; and out door jointing particularly requires extraordinary skill and care.

In making joints in underground wires, the joint box is first opened, and the jointer's tool-box placed close to one side of the hole. Attached to the box are two low stools for the jointer and his assistant to sit upon, to keep them clear from the wet pavement or damp ground. The box is opened, and the various tools, spirit lamps and furnaces placed where most handy. The spirit lamp for the furnace is first lighted and the soldering-iron heated; and the gutta percha tools, if dirty or sticky with compound, are filed and cleaned. Great care is taken to keep the gutta percha sheeting clean.

The wires leading in one direction are then taken out and prepared for jointing, by stripping off the tape for about fifteen

inches back, and fastening the roll round the cable or wire by loosening the numbers and passing them along the wire to the tape, where they are fixed by squeezing them with pliers on one side only, so as to bind evenly all round. When each wire has been served in this way the whole of them are cut to exactly the same length.

When this has been done on one side, the jointer does the same to the wires leading the other way. The wires on both sides are then thoroughly cleaned with naphtha, until each wire becomes entirely clear from dirt and tar.

After cleaning the wires the jointer very carefully cleans his own hands and dries them well. A little naphtha cleans the hands better than anything else.

The wires are then ready for jointing. No. 1 wire is then taken up on both sides (it is best to begin with the lowest number and proceed in regular order) and the gutta percha carefully trimmed off each end for about 1½ inches, care being taken that the knife does not nick the copper; when this does happen the copper is cut off at the nick, and the percha trimmed back. The copper wire left bare is scraped carefully, so as to make it bright, and then the two ends being brought together and overlapping are held by the pliers, and first one side twisted, then the other. The double twist should appear as one uniform twist, perfectly regular, and take three turns each side, or about ¾ inch in length; the surplus ends are then cut carefully and close over, and, being lightly touched with the pliers, turned in, so as not to leave any edge sticking up above the twisted joints.

The joints are then soldered, care being taken to knock off any superfluous solder. Great care is taken when soldering a joint that no wires be immediately under it, as hot solder dropping on gutta percha at once heats and penetrates it.

The remainder of the wires are then jointed and soldered. Great care is exercised in jointing similar wires; the jointer himself sees that the numbers correspond and does not trust to his assistant.

The gutta percha jointing is then commenced and the second spirit lamp lighted for warming the material. The ends and soldered joint are first cleaned with naphtha, then a stick of compound is warmed and a small quantity put on the joint and properly tooled over, so as to cover the joint equally. Before applying the tooling iron it is carefully wiped.

The ends of the gutta percha are then slightly warmed and the actual end nipped off with the fingers. One side of the percha is then well warmed for about two inches back, and then brought forward over the joint to the opposite side with a twisting motion by the moistened fingers; the opposite end, after heating, should then be brought forward over the other part in a similar manner as far as it will go, and the percha is again warmed and kneaded with the fingers and thumb.

After kneading it, it is again warmed slightly with the spirit lamp. The compound is then heated and applied over the gutta percha, by putting the compound stick on the percha, and rolling it along. The compound is warmed and applied a sufficient number of times to go thoroughly over the percha. The joint is again warmed and the compound properly tooled until it covers the joint uniformly.

A sheet of gutta percha, well cleaned (the gutta percha sheeting as supplied to jointers is cut into strips four inches long and kept carefully in a bag or case), is then warmed, and a piece of about one inch long cut off with a pair of scissors, whose edges are moistened against the lips. The joint is then warmed with the lamp, and also the piece of sheet, which is then applied to one end of the joint, half an inch on the old core beyond the pull down, and being firmly pressed, is drawn along the length of the joint to an equal distance on the other side. The superfluous end is then cut off, the joint is next turned over and the spirit lamp applied, so that the heat warms both the joint and the sheeting. The sheeting is pinched round the joint and slightly pulled, so as to make adhesion better. The spare sheeting is then cut off with the moistened scissors close to the joint, and a warm tool passed over the seam, so as to open it again,

when it is again pinched up, thus forcing out any air that may be in it. In pinching up the last time one edge ought to overlap the other slightly, so that the warm tool may properly seal up the seam. By cutting off the sheet too far from the joint the seam cannot be reopened, and by cutting off the sheet too close no seam is left, and there is necessarily a vacant space in the second covering; this is a frequent fault and should be avoided. By use of the tool the ends of the coating are made to amalgamate with the old material. The joint is then warmed thoroughly and kneaded with the thumb and forefinger, care being taken to preserve its shape, and to knead evenly all around. It is then rubbed with the moistened hands.

The stick of compound and the joint are again warmed, and the compound is rolled over the joint from end to end. The joint is again warmed and the compound is worked and spread over it, by means of the tooling iron, in an even and uniform manner. The joint is again manipulated with the fingers, and then heated for the last time and rubbed well with the hand moistened. This rubbing must be done uniformly and equally all round. It tends to solidify the joint and gives it that highly polished and finished appearance so characteristic of the handiwork of a good jointer. The best thing found for moistening is saliva.

TESTING OF UNDERGROUND WIRES.

The separate wires or cables must be carefully examined previous to their being delivered to the workmen who make the joints, and after the wires are joined, a test should be made of the different series of joints.

The work is divided into sections, varying in length according to the number of wires; at the end of each section the wires are not joined. In the other boxes or places where the junctions should be made, the wires are joined, with the exception of wire No. 1, whose extreme ends are closed up, that is to say, covered with gutta percha.

In the first box, No. 1, the different wires are connected to-

gether in the following order: 1 to 2, 3 to 4, 5 to 6, 7 to 8, 9 to 10. Tests are then made from the opposite end of the section (box No. 10), in order to see whether the loops in No. 1 are properly arranged, and whether the resistance of the copper and the insulation of the different wires are in good order. The extreme ends of the wires are then joined in box No. 10 in the following order: 2 to 3, 4 to 5, 6 to 7, 8 to 9 and 10 to 1.

Each section is arranged as in the diagram, fig. 193.

It will be seen, in this plan, that the section represents a continued circuit, commencing and ending with wire No. 1, but only interrupted on No. 1 at each box.

The batteries and testing instruments are conveyed to box No. 2 to test the first series of joints. The joints are taken out, prop-

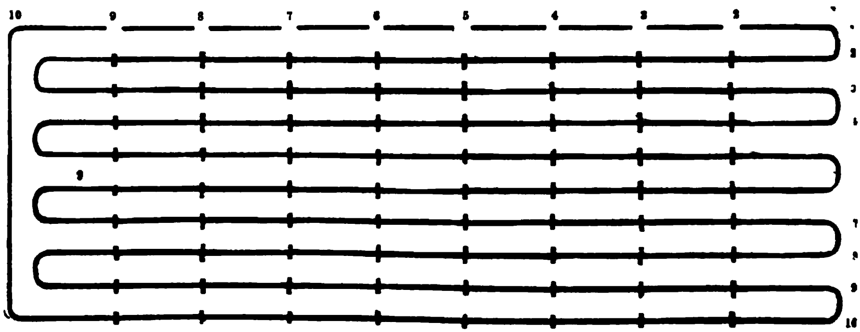


Fig. 193.

erly cleaned, then put in an insulated metallic trough, partially filled with water, and placed on the top of the box or in the most convenient position; but great care should be taken that the trough be properly insulated, and the portion of the gutta percha which touches the trough be perfectly clean.

The closed extreme end of wire No. 1, which ends in box No. 1, is then opened, and the conductor connected to the instruments. Next a very careful examination is made of the insulation resistance of the entire section, noticing the exact deflection of the galvanometer needle; the wires are discharged, and the metallic trough connected with the earth. A new test is then made, and if any increase appears in the deflection it is caused by defective

joints. The latter may be detected by putting the joints in water one after another. The first test serves the purpose of determining the insulation of the entire section, *independent* of the series of joints to be examined, the latter being themselves insulated. The second test determines the insulation of the entire section *with* the series of joints. A defective joint immediately increases the deflection.

After the joints have been tested, the wire No. 1 is connected again for continuing the circuit, and the operation is repeated at the following box. When the last box has been tested, and wire No. 1 has been joined, it will be seen that the section forms a perfect continuous circuit.

Sometimes this process is slightly modified, when the deflection resulting from the loss of current is considerable. In such a case the slight increase caused by an insufficient joint cannot be noticed. The joints are put in the insulated trough and constantly charged with electricity by means of a powerful battery, the trough being brought in communication with a wire which connects with the earth through a delicate galvanometer. The wire being charged, the current which has just escaped goes to earth through the galvanometer, which indicates its presence. In this test is not included the loss of current which is produced on the entire length of the wire, but only the direct loss which is caused by the joints placed in the trough; the defective joints are thus easily discovered.

The insulated trough used for these tests is made of copper. It is two feet long and eight inches in width, and ten inches in depth. It is insulated by means of four ebonite feet, and provided with a screw on one of its sides for the holding of the wire.

The testing instruments, batteries, and other electrical apparatus, were fitted up in a travelling van or carriage, so that the whole affair could be transported from place to place with great facility. The arrangement of the connections in the van is shown in fig. 194. The wire marked No. 1 lead, is connected to one battery key, and the earth wire to the other. The two poles of

the testing battery were connected to the apparatus, as shown in the figure, so that the depression of the right hand key sends a zinc current (—) and the left hand key in like manner a copper current (+).

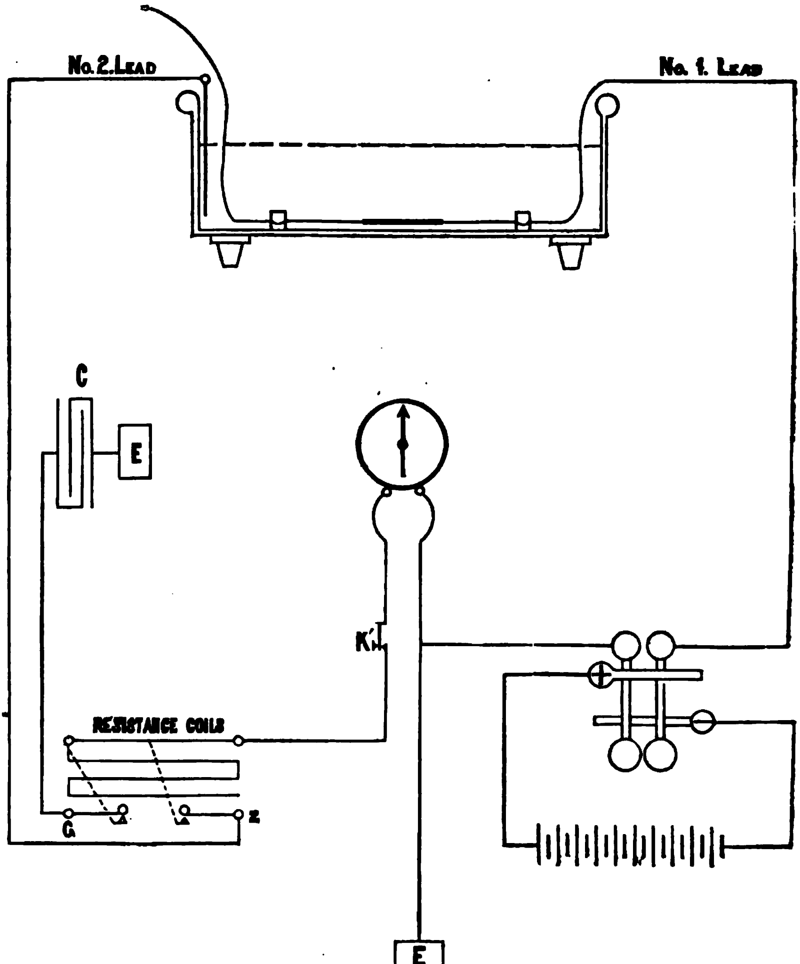


Fig. 194.

No. 2 lead was connected to the battery key of the resistance coils, which acted as a switch, the left hand or galvanometer key

being connected with the condenser (the opposite plates of which were to earth), the bridge portion of the coils being in connection with the two keys (when depressed), was joined to the Thomson reflecting galvanometer, whose other pole was to earth.

A depression of the key *z*, of the resistance coils, would at once place the trough in connection with the galvanometer to earth; any deflection (+) would at once show that there was a leakage in the trough or over the cable. This had to be remedied before the tests could be taken. If no deflection was observed, the tests were proceeded with. The whole cable is then raised to the potential of the testing battery, and the joints as well. If the joints be faulty they must leak, and some of the current must be continuously passing into the water.

In testing, the key *z* is depressed so as to put the trough to earth through the reflecting galvanometer; the battery key is then depressed and the cable charged; the inductive effect on the trough is at once seen on the galvanometer by its sudden deflection. The cable is still kept charged, and after the inductive effect is over, the scale is watched to see if the spot remains at zero, or is deflected in the same direction as the inductive charge. If there should be a deflection, then there is what is termed direct leakage through the joint; if not, then the amount of accumulation is tested. The galvanometer circuit is then broken at K′, and both G and *z* keys of resistance coils depressed for a definite period—60 seconds; the leakage from the joints, however small, then passes into the condenser, where it is accumulated; at the end of the 60 seconds the key *z* is lifted, and the condenser charge is passed through the galvanometer to earth. According to the amount of the discharge, so is the quality of the joints.

If the discharge is too great, or there is a direct loss through the joints, the joints are taken out of the trough and put back one at a time in regular order; the discharges from each were observed and noted, the bad joints being marked for removal.

It is a peculiarity in testing a number of joints so placed, that the accumulation obtained from the whole of the joints is always less than the sum of the accumulation of the individual joints.

The van containing all the batteries becomes, with one pole of the battery to earth, to a certain extent electrified. This may be particularly noticed with regard to the condenser, which almost always has some residual charges in it, due to its being so close to the batteries. The effect of this is to introduce errors into the joint tests. This has led to the abandonment of the condenser altogether in practical work, and a long India rubber lead is now substituted, which, for facility of work, is wound on a wooden drum.

On the completion of the tests the joints are replaced in the box and the hole filled up, instruments and everything repacked, and the van moved on to the next box for further joint testing.

The second box is tested in a similar manner, and so on, until the last of the section was completed, No. 1 wire being jointed in every case, generally permanently; but, where there were a number of bad joints, this wire is only jointed temporarily, so as to keep up the connection.

As soon as the jointer has replaced the condemned joints his joints are tested (in the majority of cases), and the van proceeds to the loop box of the section for the final test of that section. When the results obtained were satisfactory, the next section was taken, preceding in a similar manner, and so on, section after section.

As a proof of the value and of the improved insulation obtained by cutting out the bad joints, two statements are given of the insulation resistance of the loops of the sections before and after the joints were cut out. In these sections every joint was condemned and cut out. In the two cases the means of the 14 wires were:

	Before joints were cut out.	*After joints cut out.*
No. 1	......111 megohms.	481 megohms.
No. 2	......110 "	480 "

After the sections had been passed, one section was permanently joined on to the next, and so on; but no section was joined on until the previous lengths had been found to be still in good condition. It will be seen, therefore, that, as a frequent test of the passed work was going on, the appearance of any fault would be at once noticed. On the completion of the work, final tests of the whole are taken and preserved for subsequent comparison.

CHAPTER XXVI.

SUBMARINE CABLES.

THE first attempts to establish telegraphic communication through insulated conductors laid under water, were made at least as early as 1839, the insulating material used being hemp or cotton saturated with asphaltum, tar and other similar substances. It was not, however, until the application of gutta percha to this purpose, that the use of submarine lines was attended with any success whatever. The first cable insulated with gutta percha, which was constructed and successfully operated for the transmission of intelligence, was laid across the Hudson River, from New York to Jersey City. in June, 1848, for the use of the Magnetic Telegraph Company. In the following January an experimental submarine cable, two miles in length, insulated with gutta percha, was submerged in England, and messages were transmitted through it. The success of this experiment led to an attempt to lay a submarine cable across the English Channel, between Dover and Calais, in 1850. This consisted of a single strand of gutta percha, unprotected by any outside coating, and worked only one day. The next cable was also laid between Dover and Calais, in 1851. This cable contained four conducting wires, was 27 miles in length, and weighed 6 tons per mile. It was protected by an armor of 10 heavy wires, and is still working, after having been down 21 years. The next long cablo was laid in 1853, between Dover and Ostend, a distance of 80 miles, and contained 6 conducting wires, and weighed 5¾ tons per mile. It is still in working order. In 1853 a cable of one conducting wire was laid between England and Holland, 120 miles, weighing 1¾ tons per mile. This cable worked for 12 years. From 1853 to 1858, 37 cables were laid down, having a total length of 3,700 miles; of which 16 are still

working, 13 worked for periods varying from a week to 5 years, and the remaining 8 were total failures.

The results of the experience obtained in laying telegraph cables in inland seas was such that little hesitation was felt in making an attempt to connect Europe and America by means of a submarine cable.

Before discussing the particulars of this enterprise, it is proper to refer to some of the considerations which must be kept in view in constructing and laying submarine telegraph cables.

It is apparent that the design and construction of a cable must vary materially with the requirements of each particular case—whether the cable is to be laid in deep or shallow water, and whether or not it will be subject to dangers of a particular nature, as these circumstances have a material influence upon the manner of constructing the cable.

In any event the conducting wires must be completely insulated from the iron envelope outside, and from each other, if a number are to be used; therefore, each wire is coated with two or more concentric layers of gutta percha. The object of the outer envelope of iron wires is to form a perfect protection for the inner core against injury from external causes, and to give the cable itself such a weight that it will rest quietly on the bottom, undisturbed by the waves and currents of the sea.

As the cable undergoes considerable strain while being laid, owing to its weight and the depth of the sea, it should possess a sufficient degree of tensile strength to guard against breakage, even when laid in the deepest water.

The metal used for the conducting wires is copper; as its conductivity is great, the wires may be made small, and will also admit of being stretched somewhat without injury.

Instead of a single wire for the conductor, several smaller wires—usually seven—are often united into a single strand, which is afterwards covered with the insulating substance.

As a submarine line is subject to so many accidents, and, after having been laid cannot readily be repaired, the insulation should be as perfect as possible. At least three layers of gutta

percha are used, and in addition to this, between the successive layers of gutta percha a peculiar insulating compound, composed of gutta percha, wood-tar and rosin is applied, which not only penetrates into the pores of the gutta percha, but also, by its adhesiveness, unites the gutta percha layers with each other.

In order to protect the conducting wires from external injury, they are finally provided with a covering of hemp, and a spiral envelope of heavy iron wires, or, in place of the latter, they are surrounded with thin copper bands, as suggested by Siemens.

The principal manufactories of submarine cables are in England, although there are other extensive establishments of this kind both in Germany and France.

The process of making telegraph cables in these establishments is as follows:

The gutta percha covered wires are first tested for conductivity and insulation. For this purpose the wires are placed in a tank of water, and left for several days; they are then tested by means of a sensitive apparatus, and if found to be free from all defects, are ready to be made into cables.

The arrangements for testing are as follows, the wire having been kept in a perfectly dry temperature for a few days, to avoid surface conduction:

The wire is placed in a coiled form on an insulated drum, B, fig. 195, and one end attached to the stem of the electrometer A, in connection with the battery of 500 cells, the end of the battery wire being covered with dry silk, so as to maintain a constant but subdued charge or tension. A small earthenware basin, C, filled with water (having connection with the earth through a galvanometer, H), is placed in an intermediate position between the drum B and the insulated drum D. The wire is then gradually drawn through the water in the basin C and wound upon the drum D. The drums and the basin are insulated by being placed upon sheets of gutta percha, E E E. If the wire, in passing through the testing basin, shows a tolerably uniform state of insulation, the needle will remain steady, but an imperfect spot or joint will cause it to fall to zero.

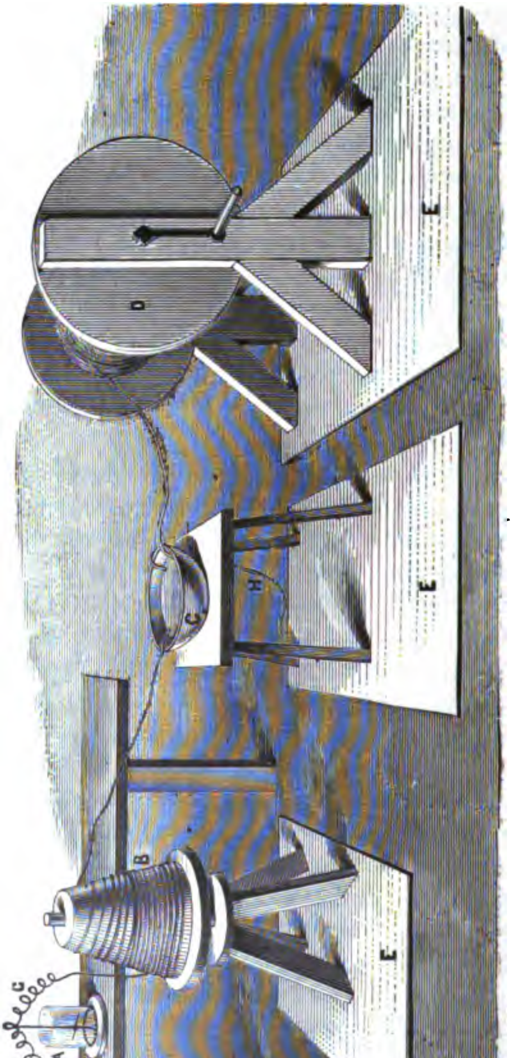


Fig. 195.

The wire is then taken from the drum and replaced in a large earthenware pan, with the exception of the defective joint, one end being, as before, attached to the electrometer, and the other insulated, and an earth wire led into the pan. Water is then gradually poured into the large pan at a temperature of 64°, but the needle shows no variation until the defective place (usually a joint) is immersed, when it falls to zero.

Between the gutta percha and the iron which forms its protecting envelope is placed a layer of hemp, technically termed the bedding. This consists of a number of separate strands, according to the number of wires which are to be covered. The

Fig. 196.

threads are wound on small bobbins, and the latter placed in the peripheries of two parallel discs, which are mounted upon a common hollow axis. The gutta percha wires, which have previously been twisted into a single strand by a suitable machine, are then drawn through the hollow axis and spun over with the hempen strands by means of the revolving discs.

This operation is well illustrated in fig. 196, and needs no further explanation. Single hempen strands are run in parallel with the gutta percha wires to fill the spaces between them, which gives the cable a perfectly cylindrical form.

The hemp serving and strands are tarred with special care, and will resist decay in water for a long time.

After the core has been covered with hemp it passes through the armoring machine, by which the iron covering is put on. This machine is similar in principle to the preceding one, but is on a larger scale; the finished cable is drawn out of the machine by means of large drums.

Fig. 197.

Instead of single iron wires for the outer envelope, iron strands are sometimes used, as shown in fig. 197.

The sheathing of the first Atlantic cable consisted of eighteen strands, each of which was formed of seven fine wires.

The principal requisite for deep sea cables is that they shall be as light, and, at the same time, as durable as possible. At first cables were generally provided with a very heavy iron sheathing,

Fig. 198.

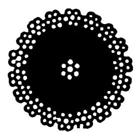


Fig. 199.

but this usually broke while being laid, as soon as the depths in which they were sunk became considerable.

The opposite course was pursued in the case of the first Atlantic cable, which was laid in August, 1858, between Ireland and Newfoundland; its weight was one ton per mile. The protecting armor consisted of strands of fine iron wires, the cable being of the form represented in figs. 198 and 199.

For the same reason the Red Sea cable was constructed as shown in fig. 200. It was found, however, that the iron wires were very soon corroded by the action of the sea water, and were finally entirely destroyed in many places. In consequence

Fig. 200.

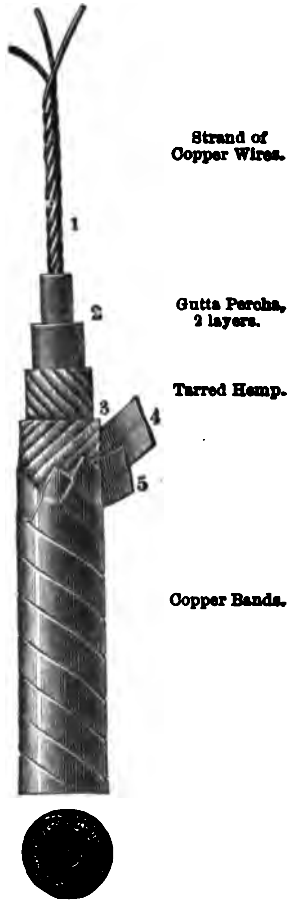


Fig. 201.

of this, each of the iron wires forming the sheathing or armor of the line from Toulon *via* Minorca to Algiers was surrounded with tarred hemp. But even this cable did not last, in conse-

quence of the attacks of a kind of worm (Xylophaga), which very soon penetrated the hemp envelope, and even bored into the gutta percha.

The same trouble was met with in the cables around which iron wires alone were wound, the worm having found an entrance between the protecting wires and eaten into the core.

In order to avoid this danger, Siemens constructed a cable on the following plan: The copper conductor is first covered with a thin layer of Chatterton's compound, and then with two spiral layers of India rubber. The second layer is put on in such a manner that its joints are at an angle of about 90° to those of the first one. The insulated core is then covered with another layer of Chatterton's compound, and again with gutta percha. The outer envelope of the cable consists of a double layer of tarred hempen bands, which are wound spirally in opposite directions, and lastly, of an outer metallic envelope, composed of two copper strips wound on spirally, so that the turns lap over each other.

A cable of this description, but somewhat simpler in construction, was laid between Biserte and Bona in 1866. Fig. 201 represents the details of this cable.

Both the Persian Gulf and Malta-Alexandria cables, represented in figs. 202 and 203, are working at the present time; the former, which lies along the Persian Gulf from Kurrachee to Bushire, is similar in construction to the Toulon-Algiers cable; but it has, in addition to the other coatings, an envelope consisting of a linen band saturated with pitch and sand.

The second Atlantic cable, which was partially laid in the summer of 1865, is represented of full size in fig. 204. The break in this cable, while being laid by the steamer Great Eastern, occurred August 2d, 1865, about two thirds of the distance from Valentia to Heart's Content, in 2,500 fathoms, or 15,000 feet of water.

The later Atlantic cables which have been successfully laid by the Great Eastern differ but little from the 1865 cable. With the latter, the hempen covering of the iron sheathing was tarred; but with the more recent cables this has been omitted, while the

iron wires composing the armor of the latter have been galvanized.

The cable which was lost in 1865 was recovered and completed to Newfoundland, and at the present time America is in

Fig. 202.

Fig. 203.

telegraphic communication with Europe by means of several cables similar to that represented in fig. 204.

In very deep water, a cable, as a general thing, is not liable to injury; in shallow water, and near the coast, however, the cable

is more subject to damage from icebergs and the anchors of vessels, as well as to the attacks of sea animals. For this reason the so-called shore ends are provided with a much heavier iron armor than that used for deep sea cables. In other respects the

Fig. 204.

shore ends have about the same dimensions as the deep sea portion to which they are joined.

Figs. 205 and 206 represent cross-sections of the shore ends of the English Atlantic cables; the former, of 1865, with a triple twisted strand; the second, of 1866, with massive iron wires, which are covered with a prepared hempen layer.

LAYING SUBMARINE CABLES.

The laying of a submarine cable is a very difficult problem, depending largely upon the proper application of mechanical principles, such as the coiling of the cable, etc., as well as the proper management of the vessel.

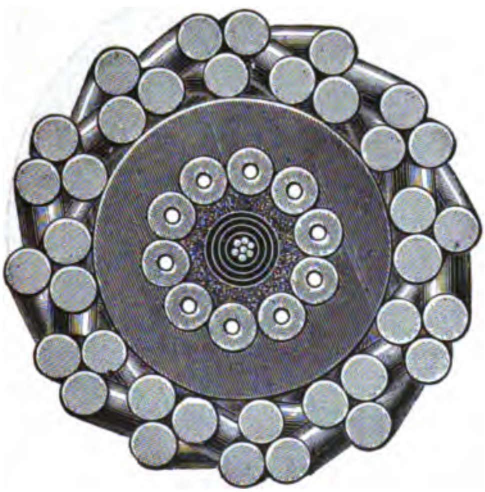


Fig. 205.

The cable is first placed on board ship, but in consequence of its enormous weight and rigidity, even this apparently simple operation, as well as the accurate coiling of the cable in the hold, is attended with much trouble.

After the cable has been stowed on board the vessel, one end of it is secured on land, and the vessel then sails over the proposed route, which has been previously well explored and sounded. The cable is gradually uncoiled and runs over the stern into the water, into which it sinks by its own weight.

During this operation it is necessary to regulate the speed with which the cable is paid out, otherwise its rate of sinking will greatly exceed that with which the ship is moving, and cause the cable to kink.

In order to regulate the speed of paying out, the cable is passed several times around one or more revolving drums. The speed with which these drums revolve is regulated by powerful friction brakes.

The force with which the brakes should be applied depends

Fig. 206.

upon the depth of the sea, which is partly ascertained by the speed with which the cable runs out, and partly by a dynamometer of peculiar construction.

A constant correspondence is maintained between the vessel and main land through the cable, and measurements of its resistance are made, which furnish the necessary information concerning its electrical condition.

We have already shown the manner in which underground wires are tested for conductivity and insulation; everything that

has there been said in regard to the conductivity of underground lines also holds good for submarine cables. In regard to the tests for insulation we must go somewhat more fully into the details of the subject, especially of the electrical resistance and electro-static capacity or condensing power of gutta percha, and the influence which this has upon the speed with which the current passes through the copper conductor.

RESISTANCE OF THE INSULATING COATING.

The resistance of conductors whose sectional area is the same throughout their entire length, is directly as the length and inversely as the section of the conductor. The case, however, is different when the conductor is of varying cross-section. In different parts of the cross-section the strength of current may even vary, as for instance when it passes laterally throughout the entire length, from the conducting wire inside through the insulating envelope to its outer surface.

Although the substances with which the conductor is covered are termed insulators, it must not be supposed that they conduct absolutely no electricity; on the contrary, they should be regarded as very poor conductors. Experience has proved that even the conductivity of gutta percha and other insulating substances in long submarine lines, where the insulating layer has considerable linear extension and proportionately little thickness, is such as to allow the passage of sufficient electricity from the copper wire to the water outside, to cause a perceptible leakage, as is proved by the use of sensitive measuring instruments.

The tests for determining the conductivity, or, more properly speaking the resistance, of the insulating coating of a cable, are of great importance, but at the same time, present peculiar difficulties.

It is first necessary to determine the specific resistance of the insulating material.

Experiments have proved that this is practically constant at any given temperature, but that it changes with the temperature. For example, between the temperatures of 5° and 27° C. the in-

sulation resistance of the cable intended for the Rangoon Singapore route decreased in the proportion of 7 to 1, consequently the loss of current at 27° was 7 times as great as at 5°.

Experiments upon the specific resistance of the insulating substance are made at a certain temperature, which is such that it will seldom be exceeded after the cable has been submerged.

The resistance of the copper conductor as well as that of the insulation, is tested in lengths of 12,000 to 18,000 feet, the result being recorded in units of resistance. Thus not only an accurate comparison between the results of the different measurements is obtained, but when the separate lengths are afterwards combined it affords a means of knowing the electrical state of the entire cable.

When the cable has once been laid, this method of measurement also enables us to determine at what point a fault occurs, as we shall show further on.

Owing to the very great electrical resistance of gutta percha, the ordinary methods of resistance measurement cannot be employed for measuring the insulation resistance of cables. A very sensitive reflecting galvanometer with an astatic needle is usually employed, having a large number of convolutions, the connections of which are arranged in the following manner:

1st method.—The galvanometer G (fig. 207) is placed between one pole of the battery B and the conductor of the cable L, the latter being submerged in a tank of water, the other pole of the battery is connected to the earth E, or with the iron tank which contains the cable. As one end of the cable is insulated, the current passes through G to the conductor, and thence through the gutta percha into the water, and thereby completes the circuit, which causes a deflection of the galvanometer needle. The question, therefore, is to determine the resistance indicated by the observed strength of current, and to reduce this to units of resistance.

For this purpose, if we indicate the electro-motive force of an element by E, the number of elements used by n, the resistance of an element by R, the unknown resistance of the insulating

coating by W, then according to Ohm's law, when S represents the strength of current, we have

$$S = \frac{n E}{n R + W},$$

or, since n R is infinitely small in comparison with W,

$$S = \frac{n E}{W}.$$

If we now indicate by α the angle of deflection of the galvanometer needle, a being a constant, then we have at the same time,

$$S = a \sin. \alpha,$$

consequently

$$a \sin. \alpha = \frac{n E}{W},$$

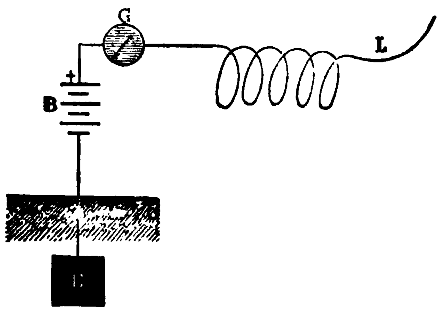


Fig. 207.

and for any other resistance W_1 and a different number n_1 of elements

$$a \sin. \alpha_1 = \frac{n_1 E}{W_1}$$

whence

$$\frac{\sin. \alpha}{\sin. \alpha_1} = \frac{n W_1}{n_1 W},$$

Now if we make $W_1 = 1$ and $n_1 = 1$ in this last equation, we shall then have

$$\frac{\sin. \alpha}{\sin. \alpha_1} = \frac{n}{W},$$

from which

$$W = n \frac{\sin. \alpha_1}{\sin. \alpha}$$

In this formula the resistance unit in which the total resistance W is expressed, is that which would give sin. α_1 with a single element. This value (sin. α_1) is called the constant of the measuring instrument.

When the measurements occupy a long time, this constant (sin. a_1) must be determined as often as the constancy of the needle may change.

This is done as follows:

Let E denote the electro-motive force of battery B, G the resistance of the galvanometer, W that of the cable, n the number of elements, and α the angle through which the sine galvanometer must be turned in order that the needle shall return to 0°. Then we get

$$\sin. \alpha = \frac{n\,E}{W + G}$$

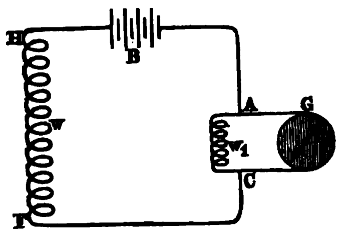


Fig. 208.

In the place of the cable we now introduce a known resistance w (fig. 208) of about 10,000 units; insert the shunt w_1, which reduces the sensibility of the galvanometer about $\frac{1}{100}$ (whence 99 $w_1 = G$), and diminish the number of elements to 1. We then have for the total strength of current

$$S = \frac{E}{w + \frac{G\,w_1}{G + w_1}}$$

and the strength of current which passes through the galvanometer when $\varphi°$ is the angle of deflection.

$$\sin. \varphi = \frac{w_1}{G + w_1} \cdot \frac{E}{w + \frac{G\,w_1}{G + w_1}}.$$

As, however, $G = 99\, w_1$, we find also

$$\sin.\ \varphi = \frac{1}{100} \cdot \frac{E}{w + \frac{99}{100} w_1}$$

Suppose, for instance, that with a certain galvanometer $\frac{99}{100} w_1 = 70$ units; if we now make w equal to 9930 units, then we get for the constant,

$$\sin \varphi = \frac{E}{100} \cdot \frac{1}{10000} = \frac{E}{1000000}$$

or,

$$E = 1000000 \sin.\ \varphi$$

By substituting this value of E in the previous equation,

$$\sin.\ \alpha = \frac{n\, E}{W + G}$$

we shall obtain, since G is infinitely small in comparison with W,

$$\sin.\ \alpha = \frac{n\ 1000000 \sin.\ \varphi}{W}$$

consequently,

$$W = 1000000 \frac{n \sin.\ \varphi}{\sin.\ \alpha}$$

2d method.—The preceding method, however, can only be used to measure large resistances within certain narrow limits. In manufacturing a cable, the resistance of a conductor increases with the length, while that of the insulation diminishes; and, therefore, the instrument would soon become too sensitive. If, on the other hand, it was less sensitive, it might at last fail to measure the resistance correctly. In order, therefore, to keep the sensibility of the instrument invariable, Siemens wound over the coil of his sine galvanometer an additional coil, containing a relatively small number of convolutions, through which the current from a small constant battery is caused to pass permanently. The current from the main battery B (fig. 209), which serves for measuring the resistance of the insulation, passes through the original coil, G, of the galvanometer, while the current from the small battery, b, passes through the outer coil, g, in the opposite

direction, and is so regulated by an artificial resistance w_1 that it neutralizes the action of the other current on the needle, and the latter, consequently, remains in a state of rest.

When the length of the cable increases, the resistance in circuit with the outer coil is diminished until the equilibrium is again restored; and the value in units of the change of resistance being known, it is only necessary to multiply the number by the permanent proportion between the actions of the two coils on the needle in order to obtain the result desired.

Suppose that G is the resistance of the inside coil of the sine galvanometer, W the added resistance, n the number of elements

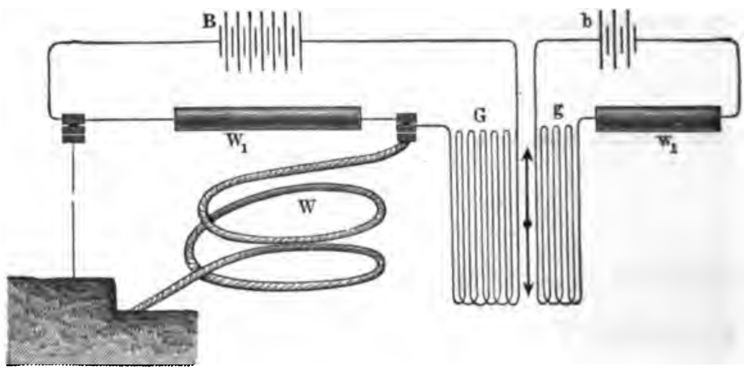


Fig. 209.

in the circuit. Again, let g be the resistance of the outside coil of the galvanometer (which for the sake of clearness is not laid over but beside it in the figure), w_1 the resistance, and n_1 the number of elements of the small battery, *b*. Let K be the coefficient or constant proportion between the action of the two coils on the needle; we then obtain for the two strengths of current,

In the circuit with battery B $\qquad S = \dfrac{n\,E}{W_1 + G},$

" " " " " $b \qquad s = \dfrac{n_1\,E}{w_1 + g};$

whence the proportion between the two strengths of current

$$\frac{S}{s} = \frac{n}{n_1} \cdot \frac{w_1 + g}{W_1 + G},$$

is easily determined, and may be indicated by K.

If in the place of W_1 the unknown resistance W of the cable is now placed in circuit, and w_1 changed to V, so that the needle again remains at rest; then, supposing that the number of elements in the batteries is changed to N and N_1, the proportion between the strength of currents which act upon the needle is obviously the same as at first, consequently

$$K = \frac{N}{N_1} \cdot \frac{V + g}{W + G}$$

whence

$$W = \frac{1}{K} \cdot \frac{N}{N_1} \cdot (g + V) - G,$$

or using the former value of K,

$$W = \frac{N}{N_1} \cdot \frac{n_1}{n} \cdot \frac{G + W_1}{g + w_1} (g + V) - G.$$

The principal advantage of this arrangement consists in the fact that the sensibility of the instrument is always the same, since the current which passes through the gutta percha acts with its full force on the needle, though the latter is always brought back to 0°. In measuring the insulation of short pieces of cable, in which case the resistance is very considerable, the resistance of both coils of the instrument (G and g) may be neglected, and we may then employ the more convenient formula

$$W = \frac{N}{N_1} \cdot \frac{V}{K}.$$

The coefficient K is independent of the sensibility of the instrument, and consequently it is only necessary to determine it once for all.

SPECIFIC RESISTANCE OF INSULATORS.

In order to determine the resistance of the insulating coating, where the current passes laterally from the conductor through

the insulating substance, let fig. 210 represent a section of the gutta percha which surrounds the conductor, whose semi-diameter O A $= r$, and let A and B be the inner and outer limits of the gutta percha, with radii r and R.

It is evident that the greater the length of the cable, the less will be the resistance which is opposed to the passage of the current, consequently the resistance is inversely proportional to the length of the insulator. If we represent the total resistance of the gutta percha by W, its length by l, and the specific resistance by s, Siemens and Thomson have shown that between these values and the semi-diameters O A $= r$, and O B $=$ R, the following equation exists:

$$W = \frac{s \text{ log. nat. } \frac{R}{r}}{2 \pi l} \text{.....................(1)}$$

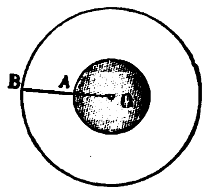


Fig. 210.

and from this we obtain the specific resistance of the insulating material

$$s = W \frac{2 \pi l}{\text{log. nat. } \frac{R}{r}}$$

According to this formula, the specific resistance S of the insulation of a cable, may be calculated when the total insulation resistance W of the cable has been determined by one of the methods described.

We may likewise ascertain from the same formula the total insulation resistance when the specific resistance is known.

The electrical resistance of gutta percha varies greatly according to its purity and the care with which it is prepared. Great attention has been paid to this point, especially by the English

manufacturers, and the insulation of the ocean cables which have been laid in latter years is far higher than that of the earlier ones. In fact the degree of insulation in the best submarine cables exceeds that of the most perfect land lines.

INSULATION TEST BY PELTIER'S ELECTROMETER.

We have seen that the loss of current in a cable, when one end is insulated and a powerful current sent into it through a very sensitive galvanometer, is measured by the angle of deflection of the needle. If we compare the strength of current passing through the insulating material with the current obtained through a known resistance, we ascertain the total insulation resistance of the cable, which we multiply by its length to find the resistance per unit of length. In consequence of the comparatively high resistance of the insulator, we may even accept this result as sufficiently accurate, for lengths of from 500 to 1,000 miles, as the proportion for the entire loss of current.

As the loss of current in short lengths of submarine cable is very small, it is perceptible only when very powerful batteries of 200 or 300 elements are used, with an extremely sensitive galvanometer, having coils of 20,000 or 30,000 convolutions. If the cable to be tested is still shorter—for instance, if only a few yards in length—even this delicate apparatus is no longer able to indicate the loss of electricity. In such cases another method is available, which may be used for any length of cable, by which we may determine the degree of its insulation. This consists in determining the time that is required for a certain quantity of electricity to escape through the insulating coating of the cable.

If we connect one pole of a battery to an insulated conductor, and place the other pole in connection with the earth, the conductor becomes charged throughout its entire length, and the potential of this charge is equal to that of the battery, so long as the connection between the battery and conductor is maintained.

This potential, which, in a battery of a few elements only, is very small, when the number of elements is increased to 200 or 300, may be easily measured by means of an electrometer.

This instrument consists, as is shown in fig. 211, of a metallic rod, M N, terminating in a brass ball, M. The lower end of the rod with its ring D rests on the pedestal P, which is insulated from the base plate A B with the greatest care, by means of a thick layer of gutta percha.

The ring D is provided with a steel point, upon which rests a long needle, consisting of a very fine aluminum or copper wire, *a b*, bent in the manner shown in the drawing, and to which is attached a

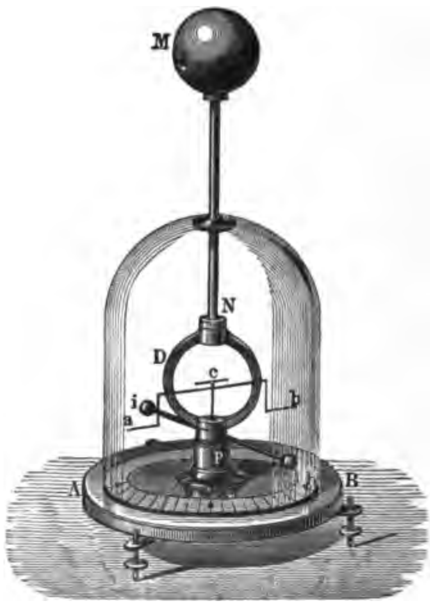


Fig. 211.

small magnet, *c*. As the latter takes up its position under the influence of the earth's magnetism, it consequently keeps the wire *a b* always in the magnetic meridian, so long as no other force acts upon it.

A horizontal metallic rod, having both its ends provided with balls *i h* is rigidly attached to the ring D.

When the instrument is to be used it is so placed that the

magnetic needle brings the ends of the wire *a b* in contact with the balls *i* and *h*.

So long as no other force interrupts the equilibrium these remain in contact, but if a quantity of electricity is communicated to the upper ball M, the charge passes over the ring D to the wire *a b* and the small stationary rod *i h*. Both become charged with like electricities, and the movable wire *a b* is repelled to such a distance that the repulsive force of the electricity and the directive force of the magnet exactly balance each other when it remains in equilibrium.

We may, therefore, determine the amount of the electric charge by observing the magnitude of the angle of deflection, which is read off the divided scale on the base plate A B. The needle *a b* should be suspended at a convenient distance from the divided circle. To prevent errors of parallax in reading the angular measures, the graduated scale is made upon a mirror. In reading off the deflection, the eye must be placed in such a position over the needle *a b* that the latter covers its reflected image; in this position it is evident that the eye is in a vertical line with the needle.

As no simple relation exists by which we may know the action on the needle of the instrument, it is impossible to determine the magnitude of the charge from the deflection alone; the instrument, therefore, should be specially graduated before being used, or an absolute scale should be determined by previous special tests and attached to it.

After the charge has been effected the ball M is connected to the earth, when the electricity flows out of the conductor and instrument, and the wire *a b*, under the influence of the magnetic needle *c*, immediately returns to its position of rest, with both of its ends against the balls *i* and *h*.

If the instrument is left to itself after charging, the electricity gradually escapes through the surrounding air; the less the escape of electricity through the air the longer the needle is in reaching its position of rest.

We thus have the means of ascertaining the decrease in the

electric tension of the ball M, by observing the rapidity with which the needle returns to its state of rest.

If the electrometer is placed in a very dry room, the discharge through the air takes place very slowly, and several hours will elapse before the needle will return to zero.

Before the instrument can be used to measure insulation it must be provided with a divided scale. For this purpose the ball M is placed in contact with the pole of a powerful battery, for instance one of 300 Daniell elements, and the deflection noted. The operation is then repeated with a battery of only half the number of elements, and the deflection again noted. The latter, of course, corresponds to half of the original electric potential. These two angles serve in all experiments made with the same battery, and under similar circumstances, for measuring any degree of insulation.

To measure the insulation of a submarine cable, we connect the conductor of the cable with the ball M, and the outer envelope with the earth, if the cable is not already immersed in water. The ball M and the conductor are then charged by placing them in connection with the pole of a battery of 300 elements; the needle *a b* is consequently deflected to exactly the same extent as in the former test, if the potential remains the same, and the cable is charged. Now, if we interrupt the connection between the instrument and the battery, the electricity in the cable gradually escapes through the gutta percha, and the needle *a b* slowly returns to its state of rest. The time is observed which the needle occupies in returning to the angle corresponding to half the original potential, or, what is the same thing, to that produced by the battery of 150 elements. In this way the time that elapses while the cable is losing half its charge is ascertained, and this is a measure of the degree of insulation. The time required for the discharge changes somewhat with the potential of the battery, as the current passes through the insulating layer more rapidly when the potential is very high. The time will, therefore, be less in proportion as the battery is more powerful. In making these tests, therefore, the strength of the battery must be taken into consideration.

A portion of the charge is also lost by escape from the ball, and through the base of the electrometer; the influence of this upon the result is especially marked when the surface of the conducting wire is small compared to that of the instrument.

The degree of insulation of a cable may be graphically illustrated by means of a curve formed by noting the seconds of the time elapsing between the charging and discharging as abscissæ, and the corresponding deflections of the gradually receding needle as ordinates.

INFLUENCE OF TEMPERATURE ON THE INSULATION OF GUTTA PERCHA.

In accordance with the investigations of Siemens and Jenkin, Bright and Clark have arranged the following empirical formula for calculating the resistance of gutta percha at a given temperature, where r represents the resistance at $t°$ C., and R the resistance at $t° + t°_1$, when the difference of temperature is $t°_1$,

$$R = r\ 0.8944^{t°_1}.$$

As a practical example, for instance, let the measured resistance of 60 miles of gutta percha insulation be equal to 30 million units at 24°; what is the resistance of one mile at a temperature of 4°?

The resistance R of one mile at 24° is evidently $60 \times 30 =$ 1800 million units; $t_1 = 24 - 4 = 20$; whence the formula gives $r = \frac{R}{0.8944^{t_1}} = \frac{1800}{0.8944^{20}} = 16.774$ million units.

The factor 0.8944, however, is not constant, but varies between 0.8944 and 0.9399, and the latter is now adopted.

By means of Table III in the Appendix the resistance of a given length of gutta percha may be easily found for a given temperature, when the same is known for any other temperature.

CHAPTER XXVII.

ELECTRO-STATIC INDUCTION ON TELEGRAPH LINES.

If an insulated cable is submerged in water, or buried in moist earth, its electrical condition when charged is similar to that of a condenser or Leyden jar (Chapter V). The gutta percha being a non-conductor, corresponds to the glass of the jar; the conducting wire within the gutta percha forms its inner coating, and the iron armor or the surrounding moisture the outer coating. When, therefore, as in fig. 212, the conductor of a submerged cable *a* is connected to the positive pole of a powerful battery B, two distinct effects are produced; in the first place the positive electricity traverses the wire in the direction of its length; and secondly, as it progresses it separates the natural electricity of the outer coating *b b*, the positive or + E being driven off, and the negative or — E bound upon its surface. The outer coating, therefore, becomes negatively electrified by induction. This lateral action, and more especially the reaction by which the negative electricity of the outer coating again induces positive electricity in the conductor, greatly retards the speed of transmission of the electric impulses through long circuits.

The distribution of the electro-static charge of a cable is not uniform at all points, but is greatest at the extremity connected with the battery, and becomes less at any other point in direct proportion to the distance of that point from the battery. When one extremity *a* of the cable, after having been placed in contact with the + pole of the battery B, is suddenly removed and placed in contact with the earth or the water P, the electricity stored up in the cable flows to the earth at both ends in order to reunite with the opposite electricity of the outer coating. This is termed the discharge of the cable, and the effect is very much

greater at the extremity a than at a'. Its direction at a is also opposite to that of the battery current by which the cable was originally charged. This return discharge from an insulated cable interferes seriously with telegraphic signals, unless special precautions are taken to avoid its effects.

The phenomena attending the charging and discharging of cables are explained by Dr. Siemens as follows:

"Suppose that a well insulated underground wire or submarine cable (fig. 212) has one of its ends a' also insulated, that is to say, disconnected from the earth plate P′, while the other end a is placed in connection with the positive pole (+) of a battery B, whose remaining or negative pole (—) is connected to

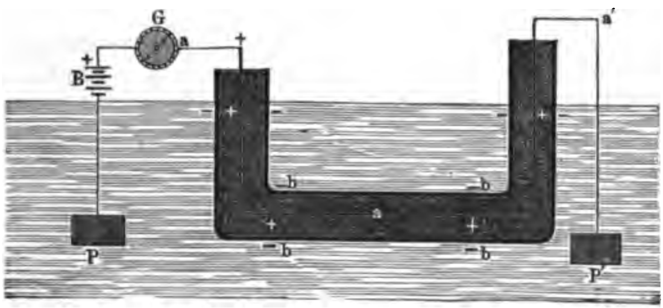


Fig. 212.

the earth at P. At the instant a conducting connection is formed between the cable and the battery B a momentary current will traverse the portion of the cable nearest the battery, the direction of which will be the same as if it had been produced by connecting the other end of the wire a' to the ground P′. In a perfectly insulated cable this current ceases almost immediately. If the battery B is now instantly replaced by a conductor, that is, if a is connected directly with the earth plate P, instead of the battery B, a second momentary current is observed almost as powerful as the first, but in the opposite direction. (The + E of the conductor a recombines with the — E of the outer coating by way of a P b). If now the cable is

again connected to the battery B as before, and then the end a is disconnected from the battery, and the other end a' being connected to the earth at P′, a momentary current again appears, but this time in the direction from a towards a', as in this case the + E of the conductor recombines with the — E of the outer coating by way of a' P′ b'. The latter experiment, of course, can only be made when two separate cables are available, which may be connected together at their remote ends, so that the ends a and a' will be situated adjacent to each other at the same station.

It will at once be seen that these phenomena are precisely analagous to those referred to in Chapter XXV, which take place upon land lines. They are, however, very much more marked in the case of subterranean and submarine conductors, because the outer coating, in the latter case, is brought in so much greater proximity to the conductor. It has been proved by experiment that the lateral accumulation or electro-static charge is from 30 to 50 times as great in a submarine cable as in a well insulated land line of the same length. The return current which is set up when the line is discharged, also lasts much longer in a cable than in a land line in consequence of its more perfect insulation. In a cable of ordinarily good insulation, half the original charge will be retained after the lapse of 20 to 30 seconds after the contact with the battery has been broken.

PHENOMENA OF CHARGE IN SUBMARINE CABLES.

The magnitude of the charge of a submarine cable depends upon the size of the conductor, the thickness of the insulating coating, and the nature of the insulating material. It increases also in proportion to the strength of the battery, and to the length of time during which the pole of the battery remains in contact with the conductor.

Gaugain, who has devoted much attention to the investigation of the details of the phenomena of inductive action in long conductors, considers that the effects of the charge are of two

different kinds: first, a momentary inductive effect, exerted in a lateral direction, which is independent of the insulating substance, and is produced by action at a distance; and secondly, a progressive polarization, due to molecular action, which advances from particle to particle through the mass of the insulating substance. While the first named action, even upon the slightest contact of the battery with the conductor, induces a charge which is independent of the substance of the insulating layer, the last named requires a certain time to penetrate through the insulating coating, and is therefore dependent upon the nature of the insulating material.

As in the transmission of telegraphic signals, the contact between the battery and the conductor of the cable is always of some duration, the nature of the insulating material is not without effect upon the magnitude of the charge. Other things being equal, the latter is found to be in proportion to the specific inductive capacity of the insulating material.

The nature of the metal of which the conductor is composed has no influence whatever upon the magnitude of the charge, but it has a very material influence upon the rapidity with which the charging and discharging of the cable takes place.

If the insulation resistance of a cable is indicated by W, its length by l and the specific resistance of the insulator by s, then

$$W = \frac{s \log. \frac{R}{r}}{2 \pi l} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If the electromotive force of the battery is designated by E, the number of elements by n, the total resistance of the circuit (including that of the battery, the conductor, and the insulating coating) by w, and the strength of current passing through the insulating coating by S, then, according to Ohm's law,

$$S = \frac{n E}{w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

And for any other current S_1, with n_1 such elements, the total resistance being w_1,

$$S_1 = \frac{n_1 E}{w_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The resistance of the insulating coating being so exceedingly great in proportion to that of the battery and conductor, we may neglect the latter without material error, and thus w and w_1 will indicate the resistance of the insulating coating, of which the value may be obtained from (1). Substituting this in (2) and (3) we obtain:

$$S : S_1 = \frac{n\,l}{s \log. \frac{R}{r}} : \frac{n_1\,l_1}{s_1 \log. \frac{R_1}{r_1}}. \qquad \ldots\ldots\ldots\ldots (3)$$

If we denote by λ the specific resistance of the insulating material, then as $\lambda = \frac{1}{s}$,

$$S : S_1 = \frac{n\,l\,\lambda}{\log. \frac{R}{r}} : \frac{n_1\,l_1\,\lambda_1}{\log. \frac{R_1}{r_1}} \qquad \ldots\ldots\ldots\ldots (4)$$

This equation includes all the laws which relate to the charge and discharge of submarine cables or underground wires.

Let us suppose the insulating coating of two cables to be of different lengths, but of the same specific conductivity ($\lambda = \lambda_1$), and that the diameters of the wire and insulating coating are the same in both cables ($R = R_1$, $r = r_1$), the latter equation then assumes this form:

$$S : S_1 = n\,l : n_1\,l_1.$$

From which it follows that the strength of the discharge and also of the charge currents, are directly proportional to the length of the cables, if the potential of the battery remains the same.

If we suppose, in equation (4), that the quantities $n\,l\,\lambda$ are the same in two cables, but that R and r are different, then

$$S : S_1 = \log. \frac{R_1}{r_1} : \log. \frac{R}{r},$$

which shows that the charges are inversely proportional to the logarithms of the quotients of the semi-diameter or radii of the insulating coating.

In order to determine directly the proportional magnitude of the discharge, it is sometimes caused to pass through a galvanometer and the swing of the needle is observed. In this case the discharge acts upon the needle like a blow against a pendulum at rest. The magnitude of the charge is, therefore, proportional to the sine of half the angle through which the needle swings.

If, therefore, we wish to compare the charges S and S_1 of two different cables, we may observe them by the aid of a tangent or sine galvanometer, according as the discharge is greater or smaller. With the sine galvanometer the formula is

$$S : S_1 = \sin. \frac{\alpha}{2} : \sin. \frac{\alpha_1}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

COEFFICIENT OF CHARGE IN SUBMARINE CABLES.

The coefficient of charge in a cable, or its electro-static capacity, is its power to receive a charge, considered with reference to a given unit of length and of potential. It may be said to designate, for each particular cable, the quantity of electricity which is stored up in each unit of its length when it is electrified to a given potential.

It is important to ascertain the coefficient of charge for all cables intended for long submarine lines, as it exercises an important influence upon the speed with which communications can be transmitted through them, and consequently upon their commercial value.

We have already seen that the respective charges of two cables may be compared by measuring their discharges. If we take two cables of different lengths, l and l_1, and charge one of them with a battery of n elements, and the other with a battery of n_1 elements, upon discharging them we obtain by the swing of the galvanometer needle the angles α and α_1; then we have as before

$$S : S_1 = \sin. \frac{\alpha}{2} : \sin. \frac{\alpha_1}{2}$$

If we indicate the coefficient of charge in one of the cables by C, and in the other by C_1, then, as S and S_1 are proportional to the quantity of electricity which passes through conductors of the lengths l and l_1, we obtain

$$S : S_1 = C\,l\,n : C_1\,l_1\,n_1 ;$$

consequently

$$C\,l\,n : C_1\,l_1\,n_1 = \sin. \frac{\alpha}{2} : \sin. \frac{\alpha_1}{2},$$

and

$$C : C_1 = \frac{\sin. \frac{\alpha}{2}}{\sin. \frac{\alpha_1}{2}} \times \frac{l_1\,n_1}{l\,n},$$

by which the relations of the coefficient of charge in both cables are determined.

If a cable is very long it does not become charged instantly, as the operation in this case requires a determinate time. If, therefore, we wish to compare the capacity of different cables which vary greatly in length, for example, of 1 and 1,000 miles, the above method is inapplicable, as it is founded on the supposition that both cables can be completely charged in the same length of time. If the length of the cable does not exceed 10 or 15 miles, the time occupied in charging and discharging it is such a small fraction of a second that the above formulæ cannot be made use of. Again, if the cable is but a few feet in length, the charge is, of course, extremely feeble, and is not sufficient to affect the most sensitive galvanometer.

By means of an interrupting wheel, however, a series of charges and discharges may be caused to pass through a very sensitive galvanometer, having 20,000 or 30,000 turns of wire, by which means a steady deflection of the needle may be obtained, even from a short length of cable.

UNIT OF COEFFICIENT OF CHARGE.

In order to be able to properly express the coefficient of charge in different submarine cables, a suitable unit of com-

parison is necessary, by which it will be possible to ascertain the electro-static capacity or coefficient of charge of a cable, Leyden jar, or any other condenser.

The coefficient of charge of any insulated conductor may be found by comparing it with the charge of a condenser composed of two plates, which are separated by a stratum of air of a certain thickness, for example $\frac{4}{100}$ of an inch, as the charge of such a condenser bears a certain definite proportion to the area of its inductive surfaces. We may, therefore, employ a condenser, the distance between whose plates is $\frac{4}{100}$ of an inch, and which has 40 square inches of surface, as a unit of electro-static capacity.

In order to determine the coefficient of charge or inductive capacity of any particular cable, it is not necessary to employ an air condenser in every instance. Standard condensers are now constructed of thin plates of tin foil, separated by leaves of paper saturated with paraffin or varnish, which will contain the same charge as the unit condenser, or a given multiple of that unit.

In speaking of the inductive capacity of cables, it is of course to be understood that they are immersed in water, or have their outer surfaces in communication with the earth in some other manner. When a cable is not immersed in water, or its outer coating is insulated from the earth, it will contain but a very feeble charge; in fact its coefficient of charge is but little greater than that of a land line of the same length.

COEFFICIENT OF CHARGE IN LAND LINES.

We have already seen, in Chapter XXIV, that the effects of electro-static induction are manifested upon land lines suspended in the air. An insulated land line is subject to electrical conditions corresponding to those of a submarine cable. The conductor is enveloped in an insulating stratum of air of more or less thickness, which separates it from the earth and from other objects in electrical connection with the earth, such as trees, buildings, etc. In places where the conductor is close to these

objects, the inductive effect is much greater than in places where it is farther from them. The conductor of a land line, being at a much greater average distance from the earth than that of a submarine cable, and the thickness of the insulating medium being also correspondingly greater, its inductive capacity per unit of length is necessarily very small in comparison.

The surface of the wire increases with its semi-diameter or radius, and consequently the inductive charge increases also in the same proportion. On the other hand, the smaller the radius the greater becomes the potential of the charge; but as the latter does not increase exactly in an inverse proportion to the radius, the practical result is that the actual charge does increase with the radius, but not in an equal proportion. For example, if a given wire is twice the diameter of another, then the charge of the former is much greater than that of the latter, although it is less than twice as great. Gaugain found that the charges of five cotton threads, having diameters respectively of 1, 2, 3, 4 and 5 millimeters, were in the proportion of the numbers 100, 113, 125, 133 and 141.

DURATION OF THE VARIABLE STATE, WHEN THE EXTREMITY OF THE LINE IS TO EARTH.

The difference between the variable and the permanent condition of the electricity in a conductor through which a current has been transmitted has already been explained at considerable length in Chapter XXIV. It will, however, be readily understood that the duration of the variable condition depends essentially upon the inductive capacity of the conductor, or in other words, upon its coefficient of charge.

It has been previously explained (see page 380 and fig. 212) how the positive electricity, in traversing a conductor, separates the natural electricity of the outer coating—the positive electricity being driven off, and the negative electricity bound upon the surface. This condensation upon the outer coating or surface advances simultaneously with the flow of the current through the conductor, the charge of the conductor and electric

potential increasing until it reaches its maximum. After this has occurred, the flow of electricity passes regularly and uniformly through the conductor to the earth at the distant end. This maximum marks the termination of the variable and the beginning of the permanent electric condition.

The greater the electro-static or inductive capacity of a conductor, the longer is the time required to charge it, or in other words, the duration of its variable condition. For two conductors of equal length and resistance, the length of the variable period is, therefore, in proportion to the coefficient of charge. The duration of the variable condition also depends upon the length of the conductor. When it is taken into consideration that a conductor twice as long as another will contain twice as great a charge, and, moreover, that the average distance through which the electricity has to pass while charging it is also twice as great, it will readily be understood that the duration of the variable period in a conductor whose length is 2, is four times as long as in a conductor whose length is 1. The duration of the variable period is, therefore, found to be in proportion to the square of the length of the conductor. A line of 300 miles requires nine times as long as a line of 100 miles to attain a permanent condition, in which the electric current flows with a uniform current after making the battery contact at each signal.

The duration of the variable condition also depends upon the specific conductivity of the metal of which the conductor is composed. Thus, in the case of two wires of different conducting power, but which are similar in every other respect, both wires will receive the same charge, but the electric impulse moves more rapidly through the better conductor, and the maximum charge is more quickly obtained. It follows from this that the duration of the variable condition in any conductor should be in inverse proportion to its resistance, and this is confirmed by the results of experience.

For similar reasons, the duration of the variable period is not the same in two conductors of equal length and similar material but of different diameter, when they otherwise have the same

inductive capacity, or coefficient of charge; a condition which may occur from inequality in the insulating coating. The duration of the variable condition in this case is inversely proportional to the sectional area of the conductor.

The electro-motive force of the battery has no influence whatever upon the duration of the variable condition. This arises from the circumstance that when a greater electro-motive force or higher potential is employed, the maximum charge is sooner obtained than with a lower potential; while on the other hand the charge is greater in the former case than in the latter, and consequently requires a longer time to reach its maximum.

Thus it will be understood from the foregoing explanations that the duration of the variable period in a conductor, or the time which elapses from the moment the pole of the battery is connected to the wire until the current attains its maximum strength, is directly proportional to the coefficient of charge in the conductor, and to the square of its length, and is also inversely proportional to its specific conductivity, and to the area of its cross-section.

If the duration of the variable condition in two different conductors is denoted by D and D_1, their respective coefficient of charge by C and C_1, their length by l and l_1, their specific conductivity by s and s_1, and the areas of their cross-sections by q and q_1; then

$$D : D_1 = \frac{C\,l^2}{s\,q} \times \frac{C_1\,l_1^2}{s_1\,q_1} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

If we furthermore indicate by M the duration of a variable condition in a conductor whose length, $l_1 = 1$, whose coefficient of charge, $C_1 = 1$, and conducting capacity $s_1\ q_1 = 1$, then in general

$$D = \frac{C\,l^2}{s\,q} \times M \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

By the aid of this formula the duration of the variable period can be found for any given conductor, when it has once been determined for any other conductor under known conditions.

If, for example, we take two wires of unequal length, sectional

area, and specific conductivity, but having the same actual resistance, then, evidently

$$\frac{l}{s\,q} = \frac{l_1}{s_1\,q_1}.$$

The relative duration of the variable period will be expressed by the equation

$$\frac{D}{D_1} = \frac{C\,l}{C_1\,l_1}.$$

If, therefore, the two wires have the same coefficient of charge ($C = C_1$), then the duration of the variable condition will be in proportion to their respective lengths.

We have seen in Chapter XXIV, page 325–6, that the duration of the variable state on an ordinary iron telegraph wire 300 miles in length, which is suspended in the air from insulating supports, may be considered to be on an average about 0.018 seconds. This would amount, for a length of one mile, to only $\frac{.018}{300} = 0.00006$ seconds. It will be seen, therefore, that a conductor of no great length, even when its resistance is very considerable, is traversed by the current almost instantaneously, and the latter attains its maximum strength in a space of time almost infinitely short.

When the sectional area and actual resistance of the two wires are both equal, according to (1)

$$\frac{D}{D_1} = \frac{l^2}{l_1{}^2}.$$

Therefore, if one of the wires is 1 mile long and the other 500, we have

$$\frac{D}{D_1} = \frac{1}{250{,}000}.$$

That is to say, the duration of the variable condition in a wire of 500 miles is 250,000 times as long as in a wire of 1 mile.

From this it will readily be understood how the duration of the variable state or time of charging may be almost impercep-

tible on a comparatively short line, while on a long line it will be very noticeable.

The duration of the variable condition upon a line depends, however, upon many other circumstances besides those which have been mentioned. For example, if the line is subject to leakages or escapes, the potential of the current arriving at the extremity of the line will be materially diminished, and so also will the duration of the variable period. The interposition of a resistance between the battery and the conductor increases the length of the variable period, as it impedes the access of the electricity to the conductor. The internal resistance of the battery has the same effect as a like resistance inserted between the conductor and a battery without resistance—that is, it increases the length of the variable period. The latter, therefore, is increased by increasing the internal resistance of the battery, but is not affected by an increase of its electro-motive force.

The resistance produced at the distant end of a conductor by a defective connection with the earth, or by the insertion of an electro-magnet, as well as the induced current set up in the helices of the latter, when its cores become magnetized, and which is of opposite polarity to the line current, have likewise an important influence on the duration of the variable condition.

In order to calculate the duration of the variable period for wires of different diameters, we assume, according to Wheatstone, that the inductive capacity or coefficient of charge, as well as the amount of the charge itself, is directly proportional to the square root of the semi-diameter or radius of the wire.

If we take, for example, a wire of 0.16 inch diameter, or 0.08 inch radius, and 300 miles in length, then if we assume, according to page 326, that $D = 0.018$ seconds; then, as $C = \sqrt{2}$ and $q = 4\ \pi$, we have for the duration of the variable condition

$$0.018 = \frac{C\ l^2}{s\ q} \times M = \frac{\sqrt{.08} \times (300)^2}{s.4\ \pi} \times M \text{ seconds.}$$

If we indicate by x the duration of the variable period on a

wire l miles in length, and $\frac{r}{100}$ inches semi-diameter, then also (as $q = \pi r^2$)

$$x = \frac{\sqrt{r} \cdot l^2}{s \pi r^2} \times \text{M seconds},$$

from which follows

$$x = 0.018 \times \frac{l}{(300)^2} \times \frac{.08 \sqrt{.08}}{r \sqrt{r}} \text{ seconds.}$$

Hence it follows that the duration of the variable condition on a line of 300 miles, and $\frac{12}{100}$ of an inch diameter, amounts to about 0.027 seconds, and for a similar line of $\frac{20}{100}$ of an inch diameter, to nearly 0.013 seconds.

DURATION OF THE VARIABLE STATE, WHEN THE EXTREMITY OF THE LINE IS INSULATED.

We have already explained in Chapter XXIV the manner in which a telegraph line becomes charged, when one of its extremities is attached to the pole of a battery whose other pole is to earth, while its distant extremity is insulated. Under these conditions the duration of the variable period is four times as great as when the distant extremity is also connected to the earth. Thus it was stated, on page 326, that in the case of an ordinary suspended iron wire of No. 8 gauge, 300 miles in length, the average duration of the variable period may be estimated at about 0.018 seconds when put to earth. When the extremity of the line is insulated it would, therefore, be $4 \times 0.018 = 0.072$ seconds. From what has been heretofore stated, it will be understood that an insulated wire or cable never attains its full charge instantaneously. Therefore, the amount of a charge in a conductor of great length cannot be measured with accuracy by the swing of the needle which takes place when it is discharged through a galvanometer, because we cannot consider the action of the electricity in this case to be that of a momentary impulse, as in the test described on page 385.

When a conductor has received its charge from the battery, and its distant end is put to earth, the charge flows out gradually

until it is entirely dissipated. If, on the other hand, the near end of the conductor is transferred suddenly from the pole of the battery to the earth, the discharge is likewise gradual, though much more rapid than in the first instance. It is impossible to ascertain with absolute certainty the exact moment when the discharge of a conductor has been completed, as it continues for some time after the flow has become so feeble as not to be capable of affecting the most sensitive instrument.

In case the discharge takes place simultaneously from both ends of the conductor, its duration is equal to that of the charge; but when the distant end alone is connected to the earth the discharge requires four times as long as the charge. If we take the case of the No. 8 iron wire 300 miles in length, the discharge in the first case would require 0.018 seconds, and in the second 0.072 seconds. In the case of a submarine cable submerged in water, the electricity penetrates through the insulating coating, and thus produces an actual leakage or loss of current. When, therefore, such a cable is discharged, the insulating coating also contains a charge of electricity, and has to be discharged as well as the conductor, part of its charge flowing outwardly to the surrounding water, and the remainder finding its way out by way of the inside conductor. For this reason, when a submarine cable is discharged, directly after the principal discharge has taken place, a weak current is always observed to continue flowing from both ends of the conductor for a certain time, the duration of which is proportional to the length of time the battery has been in connection with it. The conditions under which the insulating coating receives its charge are the same as in the case of any conductor; the greatness of the charge depends upon the length of time it has been in connection with the battery. By this action the time required to completely charge or discharge a submarine cable is sometimes increased as much as fifteen or twenty minutes.

THE TIME REQUIRED TO PRODUCE A SIGNAL.

The time which elapses between the making of contact between the battery and one extremity of the conductor, and the

indication of a signal at the other extremity, is not, like the duration of the variable condition, in proportion to the square of the length of the conductor, neither is it directly in proportion to the length, but depends materially upon the nature and more especially upon the degree of sensitiveness of the receiving apparatus to the action of the electric current. In addition to this, the time required to produce a signal is also influenced by the magnitude of the leakages of current along the conductor, and other causes, so that it is somewhat difficult to ascertain definitely the time required in any particular case. We shall, therefore, only attempt to find the average time required under the conditions usually existing in practice.

In experiments made upon a land line of 300 miles of No. 8 iron wire, such as that referred to on page 326, by means of Hughes's apparatus (which will be hereafter described under the head of type-printing telegraphs), the actual time which elapses between the closing of the battery circuit and the operation of the electro-magnet at the other extremity, was found to be from 0.002 to 0.003 seconds, and it was furthermore ascertained that this time varied nearly in proportion to the length of the line. On a similar line of 600 miles it may amount even to 0.006 or 0.007 seconds. Hughes's apparatus, however, contains a peculiarly sensitive magnet, which is affected by a current much more quickly than the ordinary electro-magnets used in telegraphy. It may be taken for granted that, with the ordinary Morse or printing instruments, the time required to produce a a signal on the electro-magnet at the extremity of a line of 300 miles of No. 8 iron wire is about 0.01 seconds, and that this time increases in a much greater proportion than the length of the line; for example, on a line of 600 miles it amounts to about 0.03 seconds.

The time required to produce a signal is very much greater than this in the case of underground and submarine lines. If we assume that the electro-static capacity or coefficient of charge is only 30 times as great as in a land line of the same length (300 miles), and of the same conductivity, it amounts to 0.09 seconds

with the Hughes electro-magnet, and 0.45 seconds with the ordinary Morse relay.

The experiments made by Hughes, showed that the time required with his apparatus to produce a signal through different lengths of a submarine cable, having a copper conductor 0.064 inches in diameter (No. 16 Birmingham gauge) and an insulating coating 0.069 inches in diameter, were as follows:

75 miles	0.025 seconds.
150 "	0.045 "
225 "	0.080 "
300 "	0.115 "
375 "	0.140 "
450 "	0.160 "

Whitehouse found, by a series of experiments on the Atlantic cable of 1858, having a conductor composed of a strand of seven copper wires, each 0.028 inches in diameter, and having three coats of gutta percha of an aggregate thickness of 0.148 inches, that the time required to produce a signal upon an ordinary relay was as follows:

145 miles	0.14 seconds.
247 "	0.34 "
494 "	0.79 "

The manifestly great discrepancy in these results is easily accounted for by the difference in the cables, and in the instruments employed. The varying conductivity of different samples of copper wire may not have been without influence upon the result.

The length or duration of the contact between the battery and the conductor has a good deal of influence upon the rapidity with which signals are produced. When the contact is broken suddenly before the permanent condition of the conductor has set in, the current cannot attain its full strength, and will be too weak to set an instrument in motion. In order to produce a telegraphic signal, it is of less importance that the current attains a certain strength, than that it acts with this strength a sufficient length

of time for the mechanical parts of the apparatus to be moved. An example of this is seen in the fact that the discharging current of a Leyden jar, even when of great intensity, is not sufficient to cause an electro-magnet to attract its armature, while a much weaker current, which continues sufficiently long, will produce this effect.

The duration of the battery contact which is required to produce a signal is, however, always less than the time which elapses between the making of the contact and the moment of the first appearance of the signal at the opposite extremity of the conductor. On a land line of 300 miles of No. 8 wire, with Hughes's electro-magnet, it amounts to about 0.003 seconds, while with the ordinary electro-magnet the time required is about 0.01 seconds.

In the case of a submarine cable, the duration of the battery contact required to produce a signal is far less than the time which elapses between the making of the contact and the appearance of the signal. In a series of experiments made upon a submarine cable of 450 miles in length, Hughes found the duration of contact required to be only 0.021 seconds, while the current did not set the apparatus in motion until 0.160 seconds after the contact was made. With an ordinary relay, the length of contact required to produce a full attraction of the armature was from 0.10 to 0.15 seconds, according to the construction of the cable, while for a galvanometer, it must on such a line amount to nearly 0.3 seconds.

The rapidity with which successive signals can be transmitted depends essentially upon the time required to charge and discharge the line. This time increases with the length and section of the conductor; moreover, as the discharge always occupies a longer interval than the charge, it follows that the signals will become indistinct at the receiving end if they are sent into the line before the discharge shall have been effected, as in this case the charge and discharge combine and cause a prolongation of the signals, causing them, as it were, to run together.

It will be readily understood from this, that the armature of

an electro-magnet or the needle of a galvanometer may be caused to move even before the current in the line has attained its permanent condition, and may in like manner return to a position of rest before the line is completely discharged.

The armature of an ordinary electro-magnet is necessarily at a greater distance from its poles at the moment when it is attracted, than at the moment when it is released after having been attracted; consequently, the strength of current which will be required to attract the armature must be much greater than that which will permit it to be released or drawn away by the retracting spring. Therefore, a telegraphic signal which is to be produced by means of the armature of an electro-magnet, cannot be completed until the current has attained the necessary strength to cause it to be attracted, and has again sufficiently diminished to allow it to be drawn away by the tension of the spring. The more nearly the values of these two strengths of current can be made to approximate each other, the more rapidly successive signals may be received. Consequently, when the receiving instrument consists of an electro-magnet, the rapidity of signaling depends essentially upon the distance of the armature from its poles, and upon the amount of play which the latter is permitted to have. The less the distance through which the armature moves, the more rapidly the signals may be made to succeed each other. The degree of sensitiveness of an electro-magnetic instrument has but little influence upon the rapidity with which the signals may be made to succeed each other. For example, let us suppose that the current in the permanent condition of the line is equal to 25, but that the armature of the electro-magnet is attracted as soon as the current has attained a strength of 10, and that it falls off again as soon as, by the disconnection of the battery, the strength of the current has diminished to 7. A distinct signal will be obtained in this case whenever the current increases from 7 to 10 and decreases again to 7. If the apparatus is made less sensitive by increasing the tension of the spring, then the current must be increased in order to overcome this tension and attract the armature. If we suppose that this attrac-

tion takes place when the current has attained the strength of 15, and that the armature is released when the current is diminished to 12; the margin will be as great, if not greater, in the latter case, and therefore the less sensitive instrument will operate at least as rapidly as the other.

In the arrangement of the electro-magnet which was invented by Hughes, the action is entirely different. In its normal position of rest, the armature is held nearly in contact with a permanent magnet, the tension of the retracting spring being increased to an extent almost sufficient to overcome the attraction of the latter. When this permanent magnetism is diminished in the smallest degree by the action of the current, the armature instantly falls off, and is afterwards replaced in its original position, not by the action of the current, but by means of a mechanical device, which is set in action by the falling off of the armature. Therefore, the sooner the current attains sufficient strength to release the armature, the quicker the electro-magnet operates.

It has thus far been taken for granted, in what has been stated, that the signals are produced by alternately closing and breaking the battery contact, forming what are in the Morse system technically termed dots, the contacts being of equal length and at uniform distances apart. The effect is somewhat different when the current is given a somewhat longer duration, in order to produce a longer signal, technically termed a dash. The greater length of time that the battery remains in connection with the line, causes the charge in this case to become much greater, and correspondingly increases the length of time which must elapse before the strength of the current will become sufficiently diminished to allow the armature to fall off. In order, therefore, to obtain distinct dashes in working the Morse system, the space of time allowed between the successive signals must be greater than when a single series of dots only is to be produced.

It will be seen, therefore, that the rapidity with which successive signals may be transmitted through long lines, especially subterranean or submarine lines, is limited, owing to the fact that the line receives a charge when each signal is sent, and that

a certain time is required to allow the line to be discharged after each signal. If the signals are made to succeed each other too quickly, one wave of electricity begins to manifest itself at the distant extremity of the line before the preceding one has completely disappeared. Hence the speed of transmission, being dependent upon the number of signals that can be sent in a given time, can only be increased by facilitating the discharge of the line.

The simplest way of accomplishing this is to put the line in connection with the earth at the transmitting station immediately upon the breaking of the battery contact, which greatly shortens the time required to effect its discharge. Another method is to attach to the line a wire in constant connection with the earth through a resistance which is so great as to interfere but little with the signals. This, of course, reduces somewhat the strength of the current which reaches the distant end of the line, but the charge and discharge is greatly facilitated by it. This explains the curious phenomenon that the rapidity of transmission on long land wires is increased by escapes and leakages along the line, provided these are not so great as to reduce too seriously the strength of the arriving current, as the charge and discharge take place more rapidly than on a well insulated line. When, however, escapes arise on land lines, in consequence of heavy rains and fogs, or on underground and submarine lines from defects in the insulating coating, by which the wire comes in direct connection with the external moisture of the earth, they divert so great a portion of the current as often to entirely interrupt the communication.

A third method of accelerating the discharge of the line, and consequently the speed of signaling, is to send a current of short duration, but of opposite polarity, into the line after each signal, which has the effect of partially discharging it. The opposing current must not be capable of producing a full and complete charge of its own, as that would in its turn require to be got rid of before another signal could be produced. It should be sufficient merely to neutralize that portion of the

charge in the first half of the cable, so that the strength of the current at the distant end will be quickly diminished at the termination of each signal, and the armature released. For this reason the opposing current should have a shorter duration or else be produced by a less powerful battery than the signaling current, especially upon long circuits.

It will readily be understood from what has been stated, that a system of transmission by means of equal alternating positive and negative currents, each of which produces a signal, as in some forms of telegraphic apparatus, is not generally an advantageous one, especially upon long circuits.

It is also apparent from the above explanations why it is possible to operate with comparatively great rapidity by means of currents produced by magneto-electric apparatus or inductive coils. It has been stated in another place that induced currents are of a comparatively high potential. Now, the potential of the electric source itself has scarcely any influence upon the duration of the variable condition in a line, notwithstanding that when the potential of the battery or of the inductor is increased, the augmentation of the current at the distant extremity is more rapid, for the reason that the height to which the current must rise to reach its maximum is increased in the same proportion. It is not necessary, however, that the current should attain its maximum; it is only required to be sufficient to attract the armature, and the higher the potential of the battery the quicker this result is effected. This may perhaps be rendered clearer by an illustration. Suppose the maximum strength of the arriving current to be 20, while the strength required to attract the armature is 10, or half that amount. If now, under the same conditions, a more powerful battery is employed, the full strength of whose current is equal to 30, this will also cause the armature to be attracted as soon as it reaches a strength of 10, which is a third of its maximum. The permanent condition is attained in the same length of time in both cases, but it is obvious that the strength necessary to cause the armature to be attracted is soonest reached in the last case.

It follows, therefore, that as the potential of the currents generated by moderately large induction coils is always very considerable, they are capable of producing a current of considerably more strength in a given time, or in other words, one which will reach the extremity of the line with sufficient strength to operate an electro-magnet in a shorter time than a galvanic current. On the other hand, as these currents are of very short duration, it is necessary that in operating subterranean or submarine lines they should have a comparatively high potential, in order that they may reach the distant extremity of the line with sufficient strength to move the instruments. The liability, however, of these intense currents to injure the insulating coating of subterranean and submarine lines is so great as to render their employment for this purpose unadvisable.

CHAPTER XXVIII.

THE EARTH A RESERVOIR OF ELECTRICITY.

WHEN Steinheil made the discovery, in 1838, that the earth might be made use of to complete the circuit of a telegraph line, he, in common with other physicists, was at once led to the conclusion that the earth actually conveyed the electric current from one earth plate to the other in the same manner as a metallic conductor, and that the resistance of the great mass of the earth was almost infinitely small in comparison to that of a metallic wire of equal length.

The experiments of Matteucci seemed to confirm this theory. He caused four wells to be dug in a straight line, at distances of 80, 30 and 50 yards from each other, and immersed in the two extreme wells two metallic plates connected with the poles of a battery of ten Bunsen's elements, while the terminals of a galvanometer were connected in the same manner with the two intermediate wells. When the circuit was closed, the needle of the galvanometer was deflected 35 to 40 degrees, from which he concluded that the current actually passed through the earth from one plate to the other. It is, however, quite possible that when the plates are at a distance of only 160 yards from each other, that the current really does pass through the earth, for it is usually easy to demonstrate the passage of a tolerably powerful current through a section of earth or of water 20 to 30 feet in length, placed in a wooden trough. But when the earth plates are several miles apart other conditions affect the result, to which these remarks do not apply.

Baumgartner entertains the same opinion as Steinheil and Matteucci, which is based upon his observation that the resistance increases with the section of earth which is interposed

between the plates. If these observations applied directly to the matter under consideration they would settle it at once, but this is not exactly the case. What Baumgartner really did was to compare the resistances of three lines when the circuit was metallic throughout, and when one part of it was metallic and the rest earth. Taking the wire as a unit he found the following proportions:

Route.	*Distance.*	*Proportion.*
Vienna-Ganserndorf, - - -	19.44 miles	3.14
Vienna-Gloggnitz, - - - -	52.36 "	6.98
Vienna-Gratz, - - - - -	134.06 "	4.70

Comparing these proportions, we at once discover that they

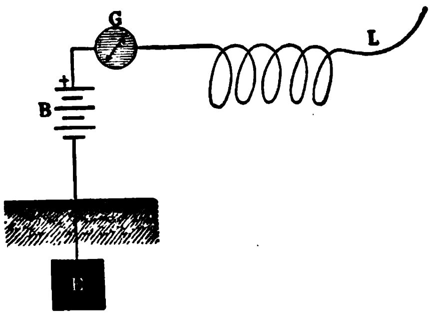


Fig. 213.

do not support the theory that the resistance of the earth increases in proportion to the distance between the plates. Baumgartner, however, concludes that this discrepancy is caused by the varying conductivity of the matter in the earth. In regard to his conclusions, Poggendorff very justly observes that the question of polarization has not been taken into account.

If we are to consider the earth as a reservoir of the electricity generated by a battery, the first thing is to prove that the battery will produce a current in the metallic part of the line without it being necessary for the earth to present a conducting medium. This proof may be readily furnished in the following way:

When one pole of a battery B (fig. 213) is in connection with the earth E, the other pole being connected to a long line L,

and a galvanometer G is inserted between this pole and the line, the electricity produced in the battery rushes into the line, and the galvanometer indicates a current which lasts until the electricity reaches the distant end. The longer the line is, the longer will be the duration of the current, and as Dub justly remarks, assuming that the velocity of electricity is 60,000 miles per second, on a wire four million miles long we would have a current for more than an hour after making the connection, without having joined the poles at all. In this case the current flows into the earth in the same way that a constant supply of water

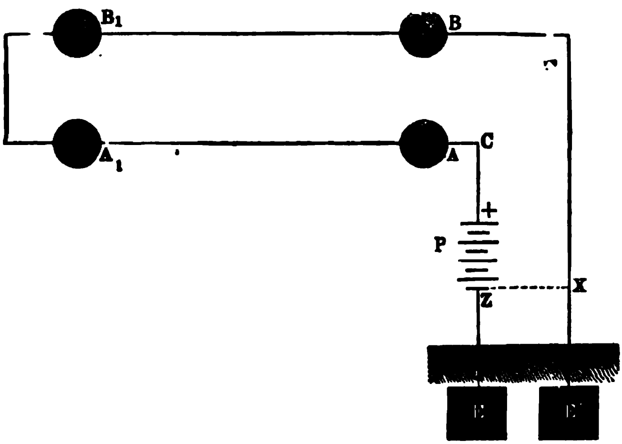


Fig. 214.

would flow into an infinitely large reservoir, without there being a possibility of any accumulation.

We see, therefore, that when we employ an infinitely large conductor, it is not necessary to make connection between the poles in order to obtain a current. As it makes no difference which of the two poles of the battery is connected to earth, it is natural to suppose that the current will pass also when both poles are to earth, without admitting the necessity of any connection between the currents through the earth.

The following experiment, the results of which strongly support the opinion that the earth acts as a reservoir instead of a

conductor, was made by Wheatstone on a submarine cable of 660 miles in length. The zinc pole of the battery P (fig. 214) was connected at Z and X with the cable, and four galvanometers, A B A_1 and B_1, were included in the circuit in such a way that the two former were in the immediate vicinity of the battery, and the other two were placed almost in the centre of the line, so that the distance between A and A_1 as well as from B to B_1, was about 330 statute miles. When the circuit was closed at C, the needles of the galvanometers A and B were deflected instantly and simultaneously, while those of A_1 and B_1 followed somewhat later.

When, however, the connection Z X was interrupted (represented by dotted lines in the figure), and the pole Z, as well as the end X of the line, was connected by means of two metallic plates E and E_1 with the earth, the result was quite different. The galvanometer A was first deflected, then A_1 and B_1, and last of all B. It follows, therefore, that the earth between E and E_1 undoubtedly performs a different office from that of the wire Z X between the same parts of the circuit, and, consequently, that it does not act merely as a conductor. It may be objected that the resistance of the circuit has been increased so much, by including the earth between E and E_1, that the relative position of the galvanometer B in the circuit has been changed. This theory, however, proves to be untenable from the fact, which is proved by experiment, that the resistance of the earth is infinitely small compared to that of a long telegraph line. Nothing, therefore, remains but the conclusion that the earth does not play the part of a conductor in the latter case. On the other hand, the phenomenon is easily explained on the supposition that the earth acts as a reservoir into which the current from the battery flows. We have already seen, when one end of a long line is insulated and the other is connected to a battery whose opposite pole is to earth, that the charge proceeds gradually from the battery end towards the end that is insulated, the flow continuing until all parts of the line have received the same potential. From this it is evident that the galvanometer

A, which is nearest the battery, should be deflected first, and that the others should follow in the order of their position.

Now, in order that the current may be continuous, it is only necessary for the electricity to be carried off as fast as it is generated in the battery, and this, in fact, is exactly what is done by the earth.

Another experiment, by Caselli, is no less decisive in its bearing on the question. If the two ends of a long air line (fig. 215) are connected to the two poles of the battery P, and two very sensitive galvanometers are inserted at B and C, the needles of both, in consequence of the derivations or leakages at the various points of support, will remain slightly deflected after the

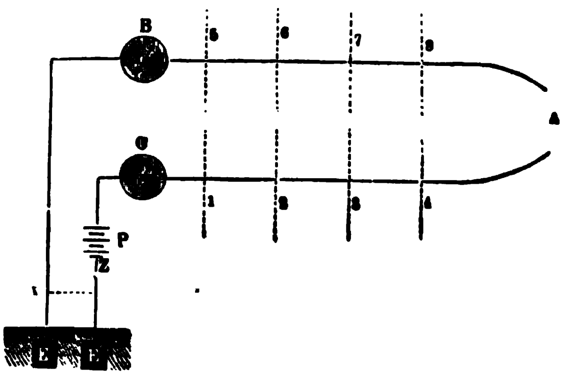


Fig. 215.

circuit has been broken at A. But if, instead of completing the circuit by a metallic conductor, as shown by the dotted lines, we connect the end x of the line to earth by the plate E and the battery pole Z to earth by the plate E_1, the result is quite different. Although nothing has been changed, except the substitution of the earth between E and E_1 for the wire Zx, it is evident that the earth does not act the part of a conductor in this case. The result, however, is easily explained if we consider the earth as a reservoir. In the first instance, when the wire Zx is in circuit, the + electricity flows through C and the derivations 1, 2, 3, 4 to earth, where it disappears; the galvanometer C is, there-

fore, deflected by a positive current; at the same time the — electricity flows through ZxB, and the derivations 5, 6, 7, 8 to earth; the galvanometer B should, therefore, show an opposite deflection, and this it does, as experience shows. If, now, we replace the wire Zx by the earth between E and E_1, the positive electricity flows as before through C and the derivations 1, 2, 3 and 4 to earth, causing a deflection at C; but the — electricity, on the contrary flows directly to the earth, and is absorbed; consequently, no electricity appears in the wire xBA, and the instrument B remains undisturbed. This experiment

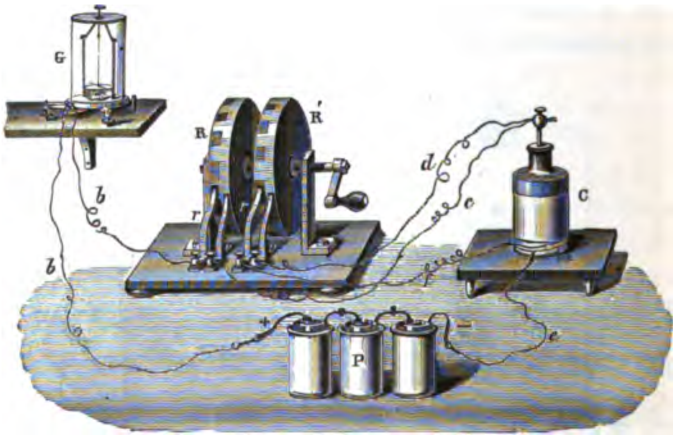


Fig. 216.

appears to show beyond a doubt that the earth acts merely as a reservoir, and, consequently, that no actual current passes from one earth plate to the other.

We are also indebted to Guillemin for a very ingenious experiment, which is a most convincing demonstration of the preceding principle. Let P (fig. 216) represent a battery and C a condenser, both of which are well insulated. Between the two is placed an interrupter with two wheels, R, R′, fixed upon the same axis. The metallic strips fixed on the circumference have an equal number of teeth, which are equally spaced and so arranged that the intervals of interruption alternate between one

wheel and the other. The interior coating of the condenser C communicates with the springs $v\ v'$ by the wires $c\ d$; the exterior coating with the spring r' by the wire f. The latter is also permanently connected with the negative pole of the battery by the wire e; finally, the positive pole of the battery communicates with the spring r by the wire $b\ b$, in the circuit of which a galvanometer, G, is placed. When the interrupter is in motion, the interior coating of the condenser communicates with the positive pole of the battery every time that the spring r passes over a metallic tooth; but r' is then on an insulated space, and the two armatures are insulated from each other. On the contrary, when r is on an insulated space, r' is on a metallic tooth; the interior coating is then insulated from the positive pole of the battery, but communicates freely with the exterior armature through the wheel R'. The result is, therefore, that during the rotation of the interrupter, the condenser C is alternately charged when r is on a metallic tooth, and discharged when r' is in the same position. Now, although the battery under these circumstances can never be actually closed, since the insulating substance of the condenser always intervenes between the ends of the polar wires, nevertheless, when a rapid rotary motion is imparted to the interrupter, the needle of the galvanometer G is deflected, and indicates the passage of a positive current from the battery to the interior coating of the condenser.

The deflection of the needle increases with the velocity of rotation; in the experiments of Guillemin it amounted to 40 degrees. In order to obtain the maximum effect, it is necessary to preserve a certain relation between the surfaces of the condenser and the power of the battery.

Whatever may be the kind of wire used for the charging circuit b, c, e, in which the galvanometer is placed, or for the discharging circuit d, f, the deflection of the needle is the same for a similar velocity of the interrupter, and the direction of the deflection may be previously known from the arrangement of the experimental apparatus.

As long as the interrupter is in motion, the charging circuit

b, *c*, *e*, and discharging circuit *d*, *f*, are traversed by a series of instantaneous electrical impulses which act on the needle of the galvanometer, and which, when the rotation is sufficiently rapid, produce the effect of a continuous current.

The coatings of the condenser, being alternately charged and discharged with great rapidity, perform the office of insulated conductors of infinite extent, one being in connection with the positive, the other with the negative pole of the battery.

Every time that the condenser is charged, a charge of electricity passes from the positive pole of the battery to the interior coating; but with apparatus of the ordinary size a single charge is insufficient to overcome the moment of inertia of the magnetized needle, and the galvanometer does not indicate its passage. With very large condensers the electricity necessary for a charge acts in a marked manner on the needle of the galvanometer.

Let us suppose that the end of a telegraph wire is connected to the positive pole of a battery, and that the other end of the wire and negative pole of the battery communicate with metallic plates or electrodes, buried in the earth. The positive electricity transmitted by the telegraph wire, and the negative from the zinc pole of the battery, pass from the metallic plates to the adjacent layers of the earth, and are instantly diffused in every direction, without producing around them any appreciable state of potential. It cannot, therefore, be considered exact to say that the current, after having passed along the telegraph wire, is returned to the battery by the earth acting as an ordinary conductor.

This opinion could only be tenable in such a case as that where the distance between the contact points of the polar wires with the earth is very small; but when the contact points are many miles apart, the terrestrial layers actually play, in respect to the poles of the battery, the part of conductors of infinite surface, which absorb the electricity as fast as it is produced, maintaining the points of the conductors which they touch at a potential of zero, and permitting the battery to work until its materials are exhausted. The earth thus opposes to the propa-

gation of the current two kinds of resistance; one passive, the resistance to diffusion, whose value depends upon the nature of the soil and the extent of surfaces in contact; the other active, due to a polarization of the electrodes, an inevitable consequence of the decomposition of liquids with which the earth is saturated. The sum of these two resistances, or the total resistance of the earth, necessarily varies according to the inverse ratio of the extent of the metallic plates buried, and to the conductivity of the surrounding layers; but for an invariable surface of the plates and for a soil of a certain nature, it evidently preserves a constant value and is independent of the length of the telegraph line. We may also add, that when communications are well established in moist earth, or still better, in a stream of water, the diffusion takes place with extreme facility, and the resistance of the earth is always small in comparison with that of a line of any considerable length.

But, however small it may be, experience proves that, on very short lines, the resistance of the earth has an appreciable value; as its value remains constant, its influence, however, diminishes as the length of electric circuit increases, and becomes too small to be taken into account when the distance between the corresponding stations amounts to 75 miles or more.

ELECTRICAL RESISTANCE OF THE EARTH.

When the electric current flows to earth and disappears, it still meets with more or less resistance in passing from the plates to the earth; but it is obvious that this resistance is quite independent of the distance which separates the earth plates, and, under like circumstances, it would preserve an unchanged value for different distances.

As the resistance of the earth is not very great, while that of a long line is usually very considerable, we may regard the earth's resistance as infinitely small in comparison, and in this case the resistance of the entire current is only half what it would be were the circuit metallic throughout. But, if the resistance of the conductor is small, we cannot assume that of the

earth to be zero without introducing an error of greater or less magnitude. According to Du Moncel's observations, the resistance of the earth, under very favorable circumstances, is equal to that of an ordinary line wire of about seven miles in length. We see, therefore, that it is not always advantageous to include the earth in circuit, especially when the resistance of the wire does not exceed that of 16,000 feet of line wire. In this case, using earth plates of 15 square inches of surface, the earth's resistance may equal that of 23,000 feet of line wire, which is large in comparison with the metallic part.

The resistance of the earth in any one case depends upon the potential of the battery current, the size of the earth plates, the conducting capacity of the earth in the neighborhood, and, even

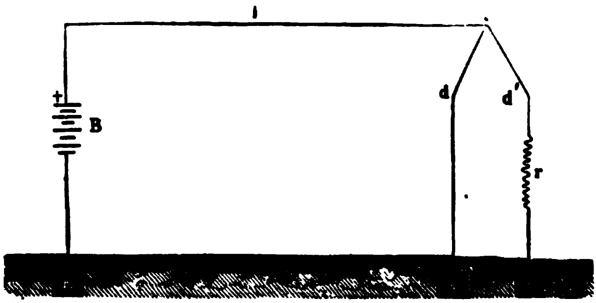


Fig. 217.

the direction of the current; for these reasons it is impossible to give a general value that will hold good for all cases; in fact, it is difficult to determine it for any one special case so long as the influence of polarization of the earth plates is unknown. When this has been ascertained, the resistance may be found, according to Nystrom, in the following manner:

Let l (fig. 217) represent a line in connection with the earth at x, this latter being the resistance which we wish to determine. Another earth plate y is placed in the neighborhood and connected to the line l at t, and the two coils of a differential galvanometer are then inserted between t and the earth plates x and y, so that the current passing from B through l, branches off at

t, part going to earth by $t\,d\,x$, the other part by $t\,d'y$. Now, as the resistance of the branch wires are equal, it is evident that $x = y$, if the needle of the instrument remains at 0°. If it does not, we must bring it back by inserting a resistance, r, in the smaller side, for instance, the one represented by $t\,d'y$; when this is done we have,

$$x = y + r \text{ or } x - y = r.$$

The resistance of the whole circuit $t\,d\,x\,y\,d'\,t$ is then measured, which gives us

$$x + y = r_1$$

and combining the two equations we obtain the values

$$x = \frac{r_1 + r}{2} \text{ and } y = \frac{r_1 - r}{2}.$$

It is here assumed that no electro-motive force is active in the circuit except that of the battery used for the test, consequently the plates at x and y should be of the same size and composed of the same metal.

CHAPTER XXIX.

EARLY EXPERIMENTAL TELEGRAPHS.

THE first attempt to construct an electric telegraph followed directly after the experiments made for the purpose of determining the velocity of frictional electricity, by Winkler, in Leipsic, in 1746, Watson, in London, 1747, and Le Monnier, in Paris, about the same time.

The earliest attempt, however, to apply frictional electricity to telegraphy seems to have been made by by Le Sage, of Geneva, who, in 1774, constructed a telegraph consisting of twenty-four insulated wires. To one end of each of these wires a pair of pith balls was suspended. Whenever the opposite ends were placed in communication with the conductor of an electrical machine, the balls forming the corresponding pair became similarly electrified and repelled each other. By this means each of the twenty-four characters forming the French alphabet could be signaled.

Lomond, with a single wire, was afterwards enabled to transmit intelligence as readily as Le Sage with twenty-four wires. This was done by using a single pair of pith balls and fixing upon a certain number of divergencies for each letter.

Reisser, Böckmann, and Salva proposed methods of signaling by means of electric sparks. These were to be grouped, after certain intervals of time, into combinations which were to represent the different characters. An apparatus for the purpose was actually constructed in 1798, by Salva, at Madrid, which gave results more or less satisfactory.

Attempts were also made by Cavallo, in 1797, and Ronalds, in 1816, to signal through long circuits by causing the discharges from a Leyden jar to traverse them. Nothing practical, however, ever resulted from these attempts on account of the numerous inherent difficulties in such a system.

APPLICATION OF GALVANIC ELECTRICITY TO TELEGRAPHY.

With the discovery of the Voltaic pile, in 1800, a new field was opened for a more practical system of telegraphy. By taking advantage of its property of effecting the decomposition of water, Sömmering, in 1808, devised a method of transmitting intelligence which had this principle for its basis. In this system 35 glass tubes, closed at one end and filled with water, were inverted over a similar number of gilded metallic strips, which passed through the bottom of a long and narrow glass trough or reservoir of water. This constituted the receiving apparatus, forming, in fact, a series of voltameters, the principle of which has been explained in Chapter XV. Each of the tubes corresponded to some letter or numeral, and was joined to the transmitting station by a separate wire soldered to the metallic strip underneath. The wires were insulated from each other, and, after leaving the reservoir, were bound into a single strand. At the sending station each wire was separately insulated and connected with a metallic terminal.

To send a signal it was only necessary to bring the two poles of a voltaic pile to two of the terminals in question. The current passing from one terminal traversed its line wire to the voltameter at the receiving station, where it passed between the gilded metallic strips corresponding to the terminals touched by the poles, and returned through the line wire to the terminal of the other pole of the pile.

When this was done, bubbles of hydrogen appeared at the metallic strip in communication with the negative pole, and bubbles of oxygen at the other one. Thus two signals were given simultaneously, of which the hydrogen took precedence. When it was desired to indicate only one letter, the positive pole of the battery was brought in connection with zero, and the negative with the letter to be transmitted. Sömmering proposed to call the attention of the receiving station by liberating an alarm by means of the accumulating gas.

In consequence of the expense which would necessarily have

resulted from the use of so many wires, which, together with its slowness of working, would have been fatal to its commercial utility, Sömmering's telegraph was never practically used.

About the same time that Sömmering invented his telegraph, the same system was proposed by Dr. J. Redman Coxe, of Philadelphia, and described by him in Thomson's Annals of Electricity, in 1810. He also conceived the idea of telegraphing by the decomposition of metallic salts, which was at a later date practically worked out by Bain.

The brilliant discovery of electro-magnetism by Oersted, of Copenhagen, in 1820, was almost immediately followed by attempts to utilize it for telegraphic purposes. The idea of suspending magnetic needles surrounded by coils of wire, in place

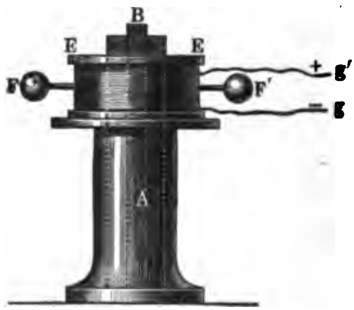


Fig. 218.

of the voltameters of Sömmering, seems to have been first conceived by Ampère, and was explained by him in a paper read before the Academy of Sciences at Paris, in 1820. This plan was afterwards carried out by Ritchie, and was publicly exhibited by Alexander, of Edinburgh.

The next important step was made by Baron Schilling, of Cronstadt, in 1832. Schilling executed models of his apparatus, which were exhibited before the Emperor Alexander. Unfortunately he died before he had practically carried out his invention. The published accounts of his system are somewhat indefinite and inconsistent, but it seems probable that he suggested both the five needle and the single needle instruments, the latter as an improvement upon the former.

Schilling's proposed plan of giving telegraphic signals with a single needle, was carried out in a more complete form by Gauss and Weber, of Göttingen, in 1833. Their apparatus consisted of a single magnetic needle, enclosed in a coil of wire, the currents being produced by a magneto-electric inductor. The latter is shown in fig. 218. A hollow column or standard, A, encloses three straight permanent magnets, B, each weighing some 25 pounds, and having their similar poles placed in the same direction. A wooden bobbin EE, provided with handles FF′, and having 7,000

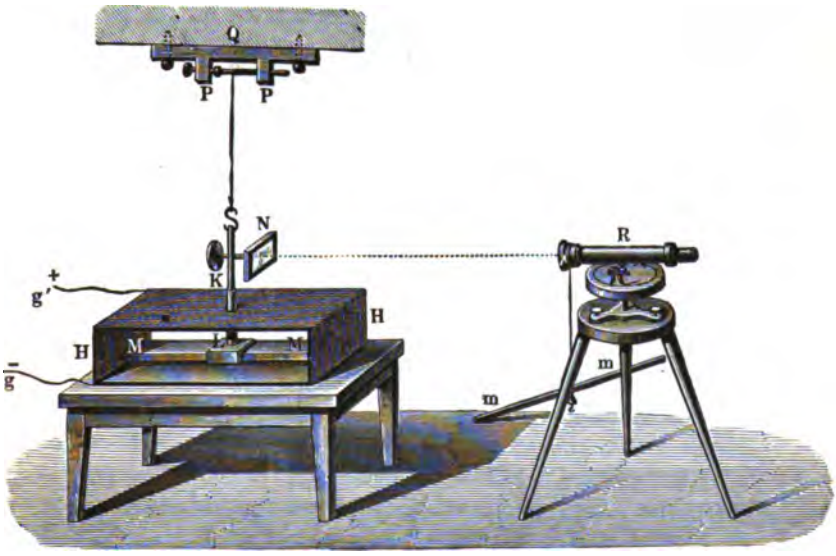


Fig. 219.

convolutions of insulated copper wire wound upon it, rests upon the top of the column A, and surrounds the magnets B, so that on lifting the bobbin by the handles a current would be induced in the coil in one direction; and on lowering it again, a current would traverse the coil in the opposite direction. The wires *gg′* were connected to a commutator, by means of which they communicated with the line wires.

The receiving instrument is shown in fig. 219. It consists of

a large coil or multiplier, HH, of insulated copper wire, the ends of which are attached at *gg'* to the line wires. A permanent steel magnet MM, 18 inches in length, is suspended within the multiplier by a number of silk fibres from the ceiling of the room. A mirror N is attached to the spindle K of the magnet, in which can be observed through a telescope, R, at a distance of 10 or 12 feet, the reflected image of a horizontal divided scale *m m*. By raising and lowering the inductor at the transmitting station, the magnetic bar at the receiving station is deflected to the right or left as the case may be. An alphabet was arranged consisting of combinations of right and left deflections, with a maximum of four elementary signals in each letter. It was only necessary that the magnet should have a very slight deflection, as the movements were greatly multiplied by the action of the mirrors and the telescope. It is this apparatus which forms the basis of the reflecting galvanometer now used in cable telegraphy.

Gauss and Weber's line was erected between the Physical Cabinet and the Observatory of Göttingen, for the purpose of experimenting upon the transmission of electric currents, and making various kindred scientific researches, but not especially for telegraphic purposes. For this reason, Gauss, unable to afford the time necessary to perfect the system, which he believed to be capable of leading to important results, requested Prof. Steinheil, of Munich, to make an attempt to simplify the apparatus and carry it out so as to make it of practical value. The degree of perfection to which this ingenious inventor brought the telegraph of Gauss and Weber was such that it may almost be regarded as a distinct invention.

For generating the magneto-electric currents employed to operate his telegraph, Steinheil made use of an apparatus consisting of seventeen horseshoe magnets, having a combined weight of 60 pounds. Two induction coils, having together 15,000 convolutions of copper wire insulated with silk, turned on an arbor and presented in rotation the axis of the coils to the poles of the magnet, so that when one coil was under the north pole of the magnet the other would be under the south pole. The

commutator in connection with these coils was so constructed that in turning them from right to left the alternate currents, that is all those of one polarity only, passed into the line, while if they were turned from left to right, only currents of the opposite polarity were allowed to go to the line, the others being cut off.

The receiving apparatus consisted of a coil of wire or multiplier of 600 turns, in the centre of which was supported, on vertical axes, two magnetic needles, their neighboring ends having opposite magnetic polarity. Figure 220 is a horizontal section of this instrument: *a b* is the coil of wire, *n s* and *n′ s′* the magnetic

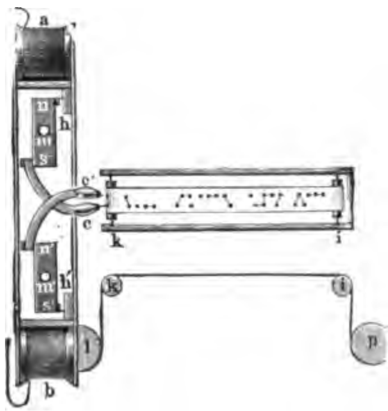


Fig. 220.

bars or needles, turning on axis at *m* and *m′*, their adjacent ends being provided with brass continuations having small ink reservoirs, *c c′*. These reservoirs were furnished with capillary tubes, and filled with ink, so that when they were brought in contact with a strip of paper travelling in front of them they would print a dot upon it. Two plates, *h h′*, prevented the needles from being deflected too far in the opposite direction, so as to be thrown into unnecessary oscillations. By means of this arrangement a current sent through the coil deflected only one of the needles at a time, the other being held back; and on a current of opposite polarity being sent, the reverse took place, the

other needle only being deflected. Thus the signals upon the moving paper were recorded in two lines, those on the right marking the right hand deflections, and those on the left the left hand deflections. The paper strip was kept in uniform motion by means of clockwork, which, whenever a mark was made, moved the paper onwards, leaving a blank space for the next signal. These marks were necessarily all dots, because of the momentary duration of magneto-electric currents.

It was a matter of considerable nicety to fix upon the proper size for the magnets, for the reason that if too large, their inertia would have been too great, while if too small, their mechanical force would not have been sufficient to effect the impression. The action of the directive force of the earth upon the needles was compensated by means of two small permanent magnets placed in the rear of the printing needles.

The arbitrary signs forming the letters of the telegraphic alphabet, were constructed from combinations of the right and left hand dots, not exceeding four in number at most. Messages were transmitted with this apparatus at the rate of a little over six words per minute.

The receiving instrument was not exclusively used to record the messages upon paper strips; sometimes small hammers were substituted for the ink reservoirs, striking against bells of glass or metal of different tones. Thus Steinheil's apparatus formed also upon occasion an acoustic telegraph.

The history of the subject thus far shows us that no single individual can justly claim the distinction of having been the inventor of the electric telegraph. Indeed, it cannot properly be said to have had an inventor. It was, in fact, a growth rather than an invention—the work of many brains and of many hands. None of the plans which we have hitherto described were ever brought into commercial use, although it is probable that had it not been for the introduction of systems and apparatus more convenient for practical use within a very short time afterwards, the ingenious invention of Steinheil would in time have met with an extended commercial application.

CHAPTER XXX.

THE AMERICAN MORSE TELEGRAPH.

In the latter part of the year 1832, Samuel F. B. Morse, an American artist, while on a voyage from France to the United States, conceived the idea of an electro-magnetic telegraph which should consist of the following parts, viz: A single circuit of conductors from some suitable generator of electricity; a system of signs, consisting of dots or points and spaces to represent numerals; a method of causing the electricity to mark or imprint these signs upon a strip or ribbon of paper by the mechanical action of an electro-magnet operating upon the paper by means of a lever, armed at one end with a pen or pencil; and a method of moving the paper ribbon at a uniform rate by means of clock-work to receive the characters. These processes, as well as the mathematically calculated signs devised for producing a permanent record, were drawn by Morse in his sketch-book while still on board the vessel. For some two years and a half after his arrival in New York various circumstances combined to prevent him from making any attempt to embody his apparatus in permanent form. In the autumn of the year 1835 he constructed the first rude working model of his invention. The electro-magnet was formed of a bent rod of iron procured from the blacksmith, the helices being composed of a few yards of copper wire insulated with cotton thread wound upon it by hand. The support upon which the various portions of the machinery were arranged consisted of an artist's stretching frame, such as is used for canvas, which was nailed against the edge of an ordinary table, as shown in fig. 221. Across the lower part of the frame a narrow trough was fastened which contained three wooden cylinders, A B C, the large one, B, being in the middle. A common

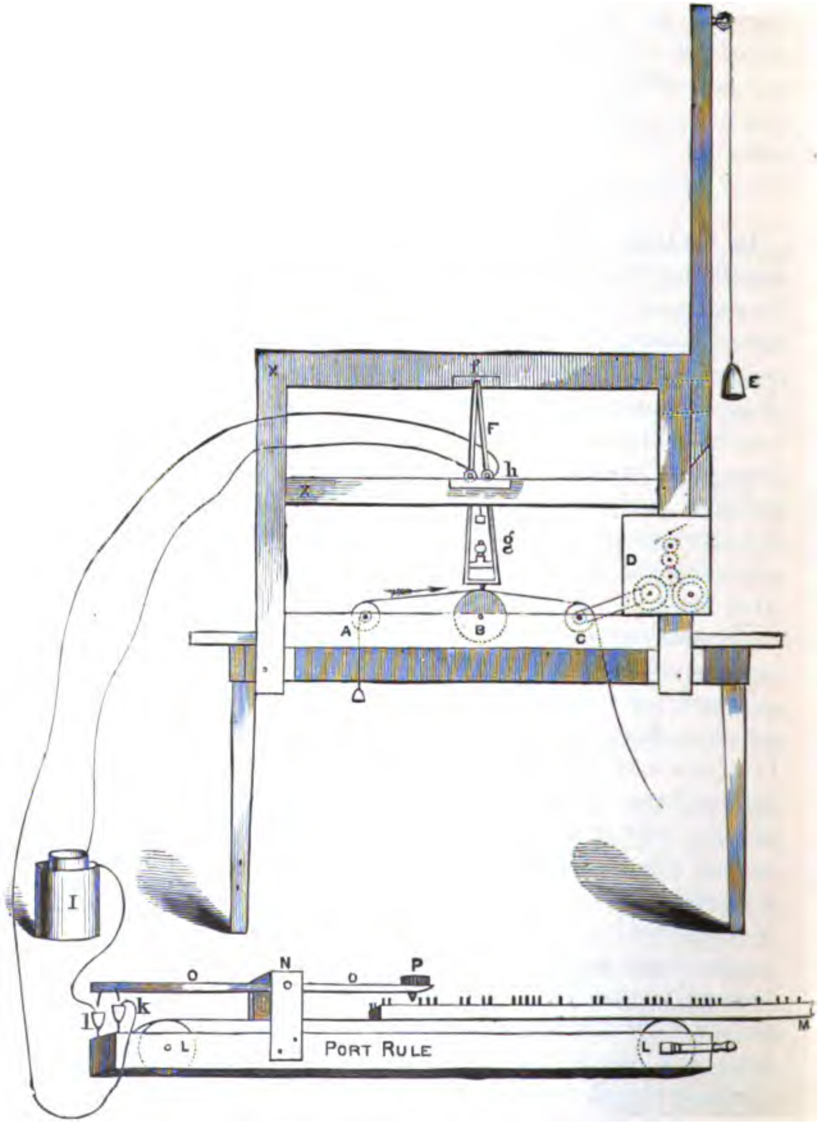


Fig. 221.

wooden clock, D, driven by a weight, E, was placed at one end of the trough, its machinery being so arranged as to turn the cylinder C by means of an endless cord. A ribbon of paper was wound upon the cylinder A, and when the clockwork was in motion it was unrolled from thence, passed over the large cylinder B, and was finally rolled up upon C. Upon the cross-bar of the frame was placed the electro-magnet *h*, which was the moving power of the marking or writing lever. This lever consisted of an **A** shaped pendulum, F, suspended by its apex, *f*, from the top of the frame, directly above the centre of the cylinder B. Through two transverse bars at the bottom of the lever was fixed a tube, *g*, within which a pencil loosely played, having a small weight upon its top to give the necessary pressure for marking. Upon the lever F, directly opposite the poles of the electro-magnet *h*, was fastened the soft iron armature. The movement of the lever was limited by stops on the frame, and the pencil was thus allowed to advance when the magnet was charged and retreat when it was discharged, the movement being through a distance of about one eighth of an inch. A small weight was at first used, and afterwards a spring, in order to draw the armature and lever away from the magnet when the circuit was broken. The battery I (a single element) was connected by wires with the electro-magnet *h* and the mercury cups *k l*. When the latter were united, by means of a forked wire upon the lever O O, the circuit of the battery was completed and the lever F drawn towards the magnet; when it was removed the circuit was broken, the magnet discharged, and the weight or spring brought the lever back to its normal position. When the clockwork was put in motion the ribbon of paper was drawn over the large cylinder B, and at the same time the pencil *g*, on the lever, being in constant contact with it, traced a continuous line lengthwise of the ribbon. When the electro-magnet attracted its armature the mark would be made obliquely across the paper, like half of a letter V; when the circuit was broken the spring would draw the lever back again, forming the other half of the V. Thus the line marked on the paper contained

the three elements of points, spaces and lines, forming by their various combinations the characters required for numerals or letters. At the time of the construction of this first machine Morse had not conceived the idea of the key now in use, the successful manipulation of which depends upon the skill of the operator, but supposed that the proper degree of accuracy could only be secured by automatic apparatus. This was arranged in the following manner: Two cylinders or drums, L L, fig. 221, were connected by an endless band of tape and turned by a crank as seen at the right. The circuit lever, O O, turned upon a fulcrum at N, and a weight, P, at the right hand end, tended to depress it, and thus to elevate the wire fork from the mercury

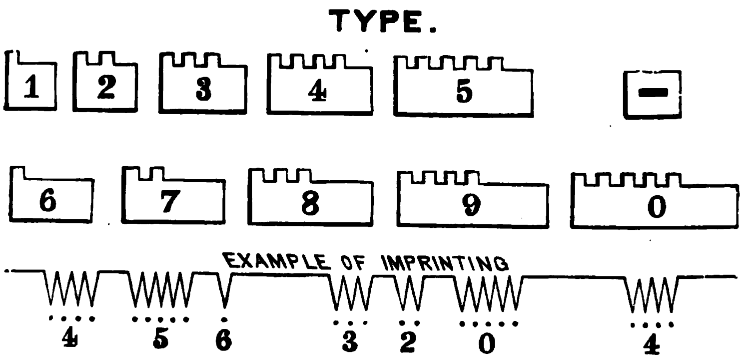


Fig. 222.

cups *k l* and break the electric circuit. M was a grooved rule for holding the metallic type, which are shown separately in fig. 222. This rule, or composing stick, having the type already set up, was placed upon the endless band, and being provided with needle points on its under side, was carried along with it when the crank was turned. As each of the projections upon the types passed under the wedge-shaped tooth upon the lever O O, it raised that end of the lever and depressed the other, causing the forked wire to dip into the mercury cups *k l*, completing the circuit of the battery, and causing the corresponding sign to be marked, upon the paper.

Such was the construction and mode of operation of the first recording telegraphic instrument. The recording instruments in use throughout the world at the present day will be found, however, to embrace precisely the same essential characteristics as this first rude apparatus. This identity of principle is more clearly apparent in fig. 223, where the pendulum lever of fig. 221 is shown as prolonged above the fulcrum *f*, and furnished with

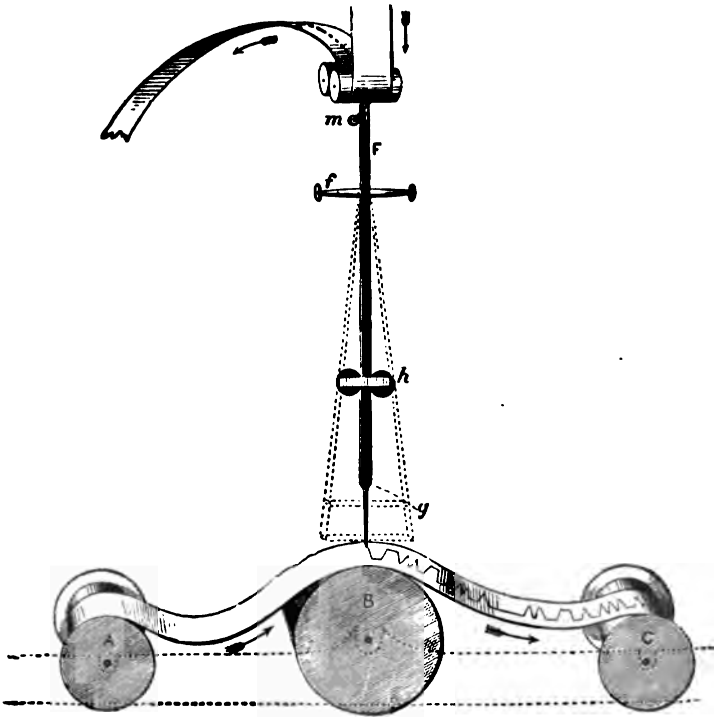


Fig. 223.

a style, *m*, so that the same movement of a single lever will simultaneously mark the modern characters upon one strip of paper and the zigzag characters originally used by Morse upon the other. The numerals shown in fig. 223 were intended to refer by numbers to the words in a telegraphic dictionary prepared for the purpose.

The first public exhibition of the above described apparatus was on the 2d of September, 1837, on which occasion the marking was successfully effected through one third of a mile of wire. Immediately afterwards a recording instrument was constructed, essentially upon the plan about to be described, which was subsequently employed upon the first experimental line between Washington and Baltimore. This line was constructed in 1843–44 under an appropriation by Congress, and was completed in May of the latter year. On the 27th of that month the first despatch was transmitted from Washington to Baltimore. Fig.

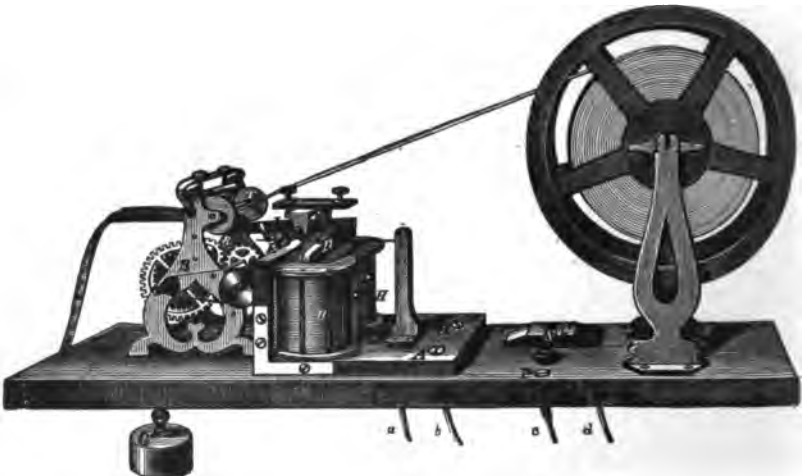


Fig. 224.

224 shows the construction of the apparatus used on the experimental line. The electro-magnet H H is mounted in an upright position upon the base A, the projecting wires forming the ends of the helices being seen at *a b*. The armature, D, is attached to one end of the horizontal lever L, turning upon a fulcrum at E. The rollers by which the paper is drawn along are driven by the clock-work R and weight G. The paper is marked by three steel points or styles, arranged side by side upon the end of the lever L, and which pressed the paper into corresponding grooves upon the roller T, thus forming embossed

characters upon its upper surface. The transmitting key was a mere flat strip of brass, S, secured at one end to a block, C; when pressed down by the finger it came in contact with the stud P, and thus formed a connection between the wires *e* and *d*. The arrangement of the circuits which was used at the opening of the line is shown in the diagram, fig. 225. B represents Baltimore and W Washington. The battery E had one of its poles attached to a plate of copper, G, sunk in the water of the harbor; the other pole being attached to the key P. The stud or anvil of the key was connected to the helices of the relay magnet R, which was a huge affair, weighing 180 pounds. The helices

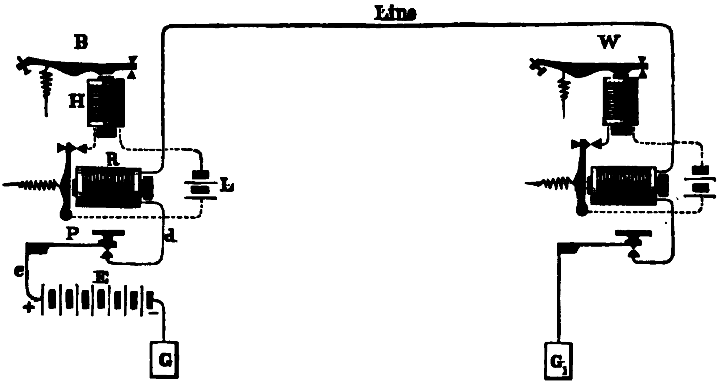


Fig. 225.

were composed of No. 16 copper wire. The line wire extended on poles from the relay magnet at Baltimore to the corresponding one at Washington, a distance of forty miles. The connections at Washington were arranged in precisely the same way, except that the battery was omitted, the wire terminating in a plate, G_1, buried in the earth. The armature of each relay opened and closed a local circuit from the battery L (represented by dotted lines), which included the helices, H, of the recording instrument shown in fig. 224. When the line was not in use the circuit was completed at both ends by metallic wedges inserted between the key P and its anvil.

The experimental line was originally constructed with two wires, as Morse was not at that time acquainted with the discovery of Steinheil, that the earth might be used to complete the circuit. Accident, however, soon demonstrated this fact, and for a time after operations were commenced only one wire was used, arranged as above stated. Afterwards a different arrangement was employed. The two wires were both connected to the positive pole of the main battery in Baltimore, and also to the earth plate at Washington. One wire had its key in Baltimore and relay and register in Washington, and the other had its key in Washington and its relay and register in Baltimore. In this way neither circuit required to be closed except when actually in use. The registers were each provided with a self-starting device, so that whenever the pen-lever moved, the clockwork would be set in motion, and the despatch would thus be written down, even in the absence of an attendant.

The plan illustrated in fig. 225 was termed the closed circuit, and the one subsequently adopted, the open circuit.

The following year (1845) telegraph lines began to be built over other routes, and as it was necessary, for the sake of economy, to put up but one wire for transmitting communications in both directions, the closed circuit plan was again resorted to, and has been employed for working the Morse apparatus on all the American lines from that time until the present.

THE MORSE TELEGRAPHIC ALPHABET.

From the brief description which has been given above of the instruments used on Morse's first experimental line, it will be understood that the action of the steel marking point or style upon the moving strip of paper above it, when actuated by the closing and breaking of the circuit of the electro-magnet, is capable of producing but two elementary signs, viz., the line and the space. It is at the same time apparent that the length of the lines and spaces may be regulated at pleasure, by varying the length of time during which the circuit which actuates the electro-magnet is closed or broken.

In the arrangement of his conventional telegraphic alphabet, Morse took as a unit of space or length the shortest available length of line, technically termed a dot. His alphabet was then made up of signs, arranged in various combinations, which, when formed into words and written out by the recording apparatus, were of the following values respectively:

The dot	= 1 unit.
The dash	= 3 units.
The space between the elements of each letter	= 1 unit.
The space between two letters	= 3 units.
The space between two words	= 6 units.

The complete alphabet, as originally arranged by Morse, and still used throughout the United States and the Dominion of Canada, is as follows:

LETTERS.

A	. —	J	— . — .	S	. . .
B	— . . .	K	— . —	T	—
C	. . .	L	———	U	. . —
D	— . .	M	— —	V	. . . —
E	.	N	— .	W	. — —
F	. — .	O	. .	X	. — . .
G	— — .	P	. . . . .	Y	. . . .
H	. . . .	Q	. . — .	Z	. . . .
I	. .	R	. . .	&	. . . .

NUMERALS.

1	. — — .	4	. . . . —	8	— . . . .
2	. . — . .	5	— — —	9	— . . —
3	. . . — .	6	. . . . . .	0	————
		7	— — . .		

PUNCTUATION, ETC.

Period	- - — — - -	Exclamation	— — — -
Comma	- — - —	Parenthesis †	- — - - —
Semicolon*	- — - — -	Italics †	— - - - —
Interrogation	— - - — -	Paragraph ‡	— — — —

It will be observed that there are six letters or signs in the American Morse alphabet, viz., C, O, R, Y, Z, and &, termed spaced letters, because they are distinguished by a space in the body of the letter equal to two units. These letters were thus arranged with the intention of securing economy of space, and consequently economy of time. The inventor was anxious that no letter should occupy more than five dots, or nine units in length; it will be perceived that none of them, with the single exception of the letter J, exceed that number.

Another principle was specially observed in the arrangement of the alphabet, that of the relative frequency of the occurrence of the various letters in the English language. The letters occurring most frequently were, therefore, composed of the fewest and shortest elements. The letter E is thus represented by a single dot; the I and T within the space of two dots or three units, and so on; none of the rest, with the single exception of J, exceeding five dots, or nine units. All the numerals were comprised within the value of six dots, or eleven units, to distinguish them the more readily from the letters.

The spaced letters were very early found to possess the practical inconvenience of being liable to be confounded with other letters or combinations of letters, unless very carefully rendered, which fact has been known to give rise to serious errors, though this has occurred much less often than would at first be supposed likely. The most common defect in trans-

* The Semicolon, Parenthesis and Italics are but little used on the American lines. The operators are accustomed to emphasize particular words by separating the letters a little more than in ordinary cases.

† These signs precede and follow the words to which they belong.

‡ Signifies begin another line.

mitting these letters is to make the space in a spaced letter exactly equal to that between the letters themselves, instead of one third less, as it should be. But it fortunately happens that the number of words in the language which are liable to be mistaken for each other when written in this way is very small. An example of two such words is found in *poison* and *person*, which it would be ordinarily very difficult to distinguish, unless the remainder of the communication furnished a clue to the meaning.

After the introduction of the alphabet into practical use, and the discovery of the above mentioned defect, Morse endeavored to modify the alphabet in such a manner as to obviate it, but was unable to overcome the prejudices of the operators against a change, even upon the first public line, and, therefore, it was reluctantly suffered to continue. Upon the introduction of the Morse system into Germany many years ago, an improved arrangement of the alphabet was devised, and this has since then been adopted in all parts of the world except America. It has been proposed to introduce the European alphabet in this country also, but though the advantages of such a reform would doubtless be numerous, yet it may perhaps be better to suffer some inconvenience from an acknowledged imperfection, than to attempt to remedy it by introducing a change that would for a time cause serious annoyance to the thousands of skilful operators now in the service.

Having thus given the history and the progress of improvement in Morse's telegraphic apparatus up to the time of its practical introduction in the United States, we will now describe the instruments and appliances in use at the present day.

THE REGISTER.

The primitive form of register or recording apparatus shown in fig. 222, and afterwards modified, as shown in fig. 224, has since undergone a number of minor improvements, but without any essential change in the principles of its construction. Fig. 226 shows a register of a more modern design, in which the parts corresponding to those in fig. 224 will be readily recognized.

The strip of paper passes between a pair of movable guides, and thence between two rollers, seen at the top of the machine. The left hand roller is carried by the clock-work, which is driven by a weight. The upper or right hand roller is carried by friction against the other, the pressure being regulated by two adjustable spiral springs, one of which is seen in front, the other being at the back of the machine. The electro-magnet, armature and pen lever are seen at the right hand. A screw in front serves to start and stop the clock-work when required. The marking is effected by a single style or point of hardened steel, fixed in the end of the pen lever, beneath the

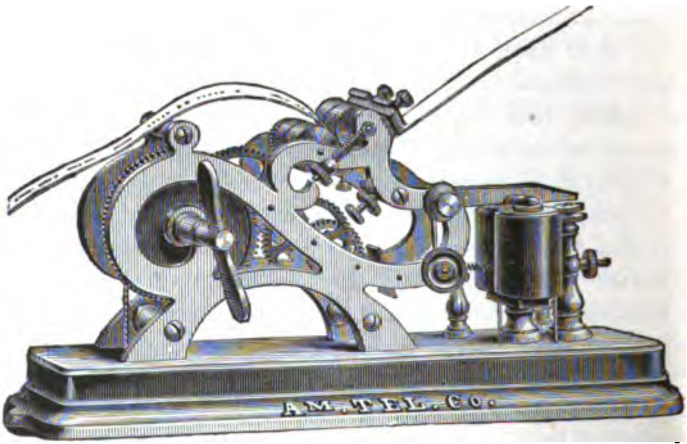


Fig. 226.

upper roller, which is provided with a groove or channel in which the marking point works. Therefore, as the paper is drawn through between the rollers at a uniform rate of movement by the action of the clock-work, a raised line will be embossed upon the upper surface of the paper, whenever the style is forced into the groove by the attraction of the electro-magnet for its armature upon the opposite end of the lever. A spiral spring, the tension of which is adjusted by a screw seen at the extreme right of the instrument, serves to draw the lever back to its normal position when the action of the electro-magnet

ceases. The play of the lever is limited in each direction by adjustable set-screws, which act as stops. By changing the position of the paper guides the same strip of paper may be used several times over, each successive line occupying a position parallel to the last one.

Fig. 227 shows the standard register of the Western Union Telegraph Company, in the improved form in which it is now manufactured. The clock-work is driven by a coiled spring instead of a weight, as in the older patterns.

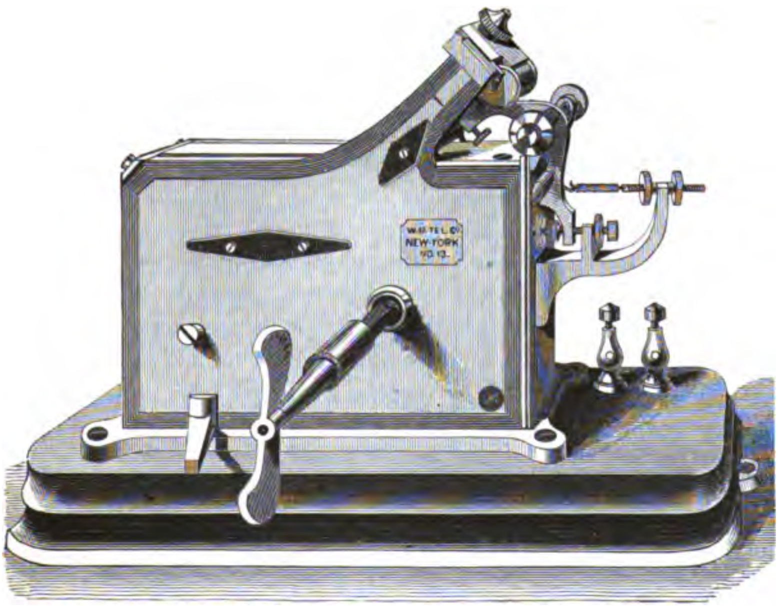


Fig. 227.

The machinery is entirely enclosed by the combined glass and brass frame, and the pivot holes are also covered, so as to keep the instrument free from dust. An extra wooden roller is attached for greater convenience of starting paper. The paper has simply to be inserted between the wooden roller and the guide above it, and pressed forward while the register is in motion, when it will feed through without difficulty. The rate of

speed may be varied by removing the glass at the left hand end of the case and turning the screw under the governor. It is not designed that the operators should take out the pen lever. When the pen or style requires adjustment it should be turned up or down by its milled head.

The electro-magnet is wound with insulated copper wire, of No. 23 gauge (0.027 inches diameter), to a resistance of about 4 ohms. In a local circuit two cells of gravity battery furnishes sufficient power to mark the paper distinctly.

In adjusting the register the armature must not be allowed to come quite in contact with the poles of the electro-magnet (which in this instrument are flush with the outer surface of the case), but should be separated by at least the thickness of an ordinary piece of writing paper. If the armature is allowed to touch, it will adhere to the poles after the circuit has been broken, and will not easily be pulled off by the action of the spring. After the set-screw which limits the movement of the armature towards the poles of the electro-magnet has been properly adjusted, the armature should be held down, either by closing the local circuit through the electro-magnet or by pressing it with the finger, while the paper is allowed to run through, and the style or pen point is adjusted by turning its milled head until a continuous mark is produced by the action of the style in the groove of the roller. This mark should not be any deeper than is necessary to secure distinctness. The set-screw which limits the movement of the armature away from the electro-magnet should finally be adjusted so as to allow the marking point to clear the paper when the electro-magnet is not in action. If the style does not work accurately in the groove of the roller the marks will be more or less imperfect. This difficulty usually arises from the screws which form the bearings of the pen lever working loose, so as to allow too much lateral play to the axis, and may be remedied by adjusting them. When once properly adjusted they should be let alone. Much of the trouble which inexperienced operators meet with is caused by the unnecessary alteration of the adjustments of the pen lever.

The register is comparatively little used in America at the present day except in the smaller and less important stations, having been superseded by the more simple and convenient sounder.

THE SOUNDER.

In the larger telegraph offices of the United States and Canada the recording instrument or register is entirely dispensed with, and all communications are read by the sound made by the armature lever as it vibrates between the upper and lower stops. Thus the sound of the pen lever of a register indicates to the ear the signs of the Morse alphabet, which are at the same time being indicated to the eye upon the moving strip of paper. The sounds of the letters hold the same relation to the written telegraphic characters that speech does to written or printed language. In writing or printing either the dot or the dash, the pen lever produces two distinct sounds, one caused by its striking against the stop, which limits its motion in one direction, and the other by striking against the stop which limits its motion in the other direction. These sounds are the natural and ordinary accompaniment of the process of writing or marking the letters. It might seem that as the making of each dash and each dot gives rise alike to two similar sounds, that one would be liable to be mistaken for the other; but the means by which a dot is distinguished from a dash does not consist in the number of the sounds, but in the difference of the interval in the respective cases between the first and second sound. In the case of the dot, the two sounds which indicate its commencement and its termination are separated by a short interval of time; in the case of a dash the sounds have a longer interval between them. This difference of interval soon becomes familiar to the ear, and enables the operator to hear as well as see a transmitted despatch. Thus the Morse apparatus produces two distinct results simultaneously, either of which suffices, and, therefore, either may be dispensed with at pleasure, or both used together. Thus the sounder dispenses with the writing apparatus altogether.

Fig. 228 represents a sounder extensively used by the Western

Union Telegraph Company. The engraving is two thirds the actual size. The helices of the electro-magnet are wound with No. 24 insulated copper wire, and have a resistance of about 4 ohms. The sounder is usually operated by a local battery consisting of a single element. It is mounted on a mahogany base, having metallic feet at each end. The electro-magnet is covered with a casing of vulcanized rubber, polished. Fig. 229 repre-

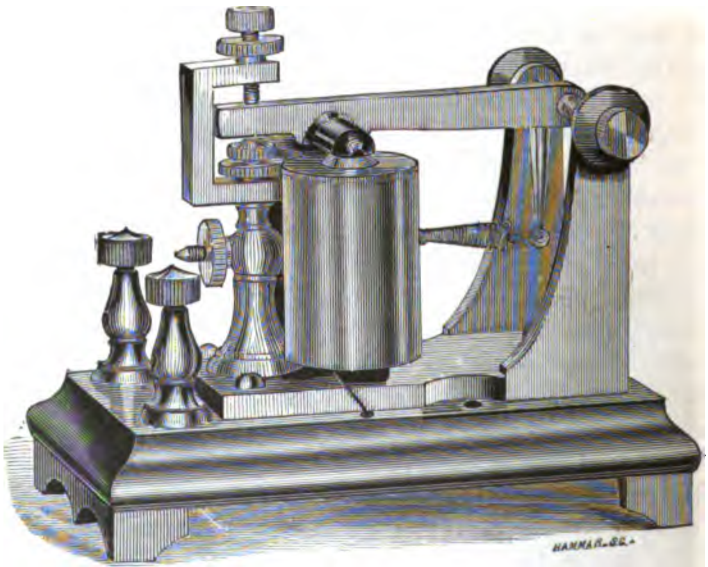


Fig. 228.

sents another favorite pattern of sounder, which is much used on railway lines, or in places where external noises are liable to interfere with the sound of the instrument. It has a very heavy armature lever, and an arch or bridge is provided upon which the downward stroke of the armature takes effect. The space between the metallic and the wooden base forms a hollow enclosed sounding box. The volume of sound produced by this combination is very great.

A number of other patterns of sounders are in use, the kind employed in any particular instance depending upon circumstan-

ces. Some operators can distinguish a light sound more clearly than a heavier one, and *vice versa*. It is essential that the sounder should be tightly screwed down to the table; the acoustic vibrations are thus communicated to the latter, which acts as a sounding board, and thence to the ear.

The registers and sounders which have been described are worked either by a local battery and relay or directly by the main line current, the former being the most common arrangement. When intended for direct working, their helices are usually wound with wire varying in gauge from No. 24 to No.

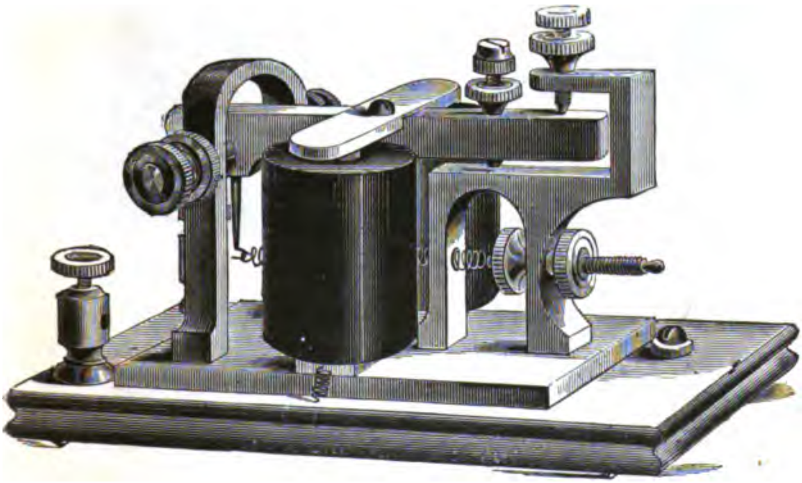


Fig. 229.

32, and even 36 Birmingham gauge, according to the length or resistance of the circuit in which they are intended to be used. Generally speaking, it is not advantageous to attempt to work an embossing register at a distance of more than 20 or 30 miles, or a sounder more than 50 miles, without the intervention of a relay. Fig. 230 represents a convenient and compact form of main line sounder with a key attached, forming a complete apparatus for sending and receiving communications. The engraving is nearly the actual size of the instrument. The whole arrangement is packed in a small case, and can be readily carried in the pocket.

Fig. 231 is a different arrangement, designed for the same purpose, the engraving being about one half the actual size of the apparatus. These portable instruments are much used by line

Fig. 230.

repairers and operators in the military service, and are very convenient and serviceable. An instrument similar to the one shown in fig. 231, but of larger size, is much employed in the railway

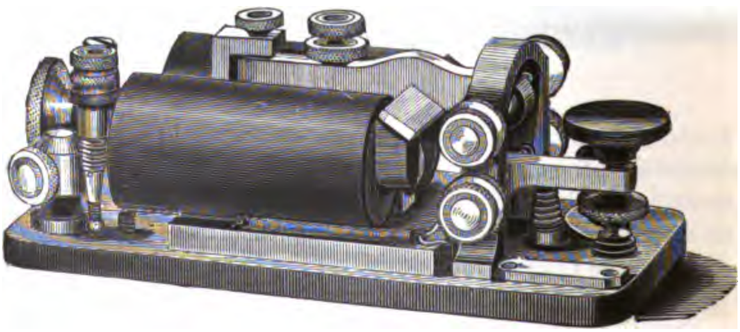


Fig. 231.

telegraph service, for establishing a temporary office at points where the track has been obstructed by accident, which is often an indispensable measure for securing the safety of trains.

When a line is of considerable length and resistance, or its insulation is very defective, the main line current is usually too feeble to work a register or sounder direct with the necessary power. This is the case in the majority of instances in practice, and recourse is then had to the receiving magnet or relay, which is placed in the main circuit, and merely performs the duty of opening and closing the circuit of a local battery at the receiving station, which in turn operates the register or sounder.

THE RECEIVING MAGNET OR RELAY.

The receiving magnet, or as it technically termed, tne relay, consists of a bar or armature so arranged as to be free to move when acted upon by an electro-magnet, and which when moved

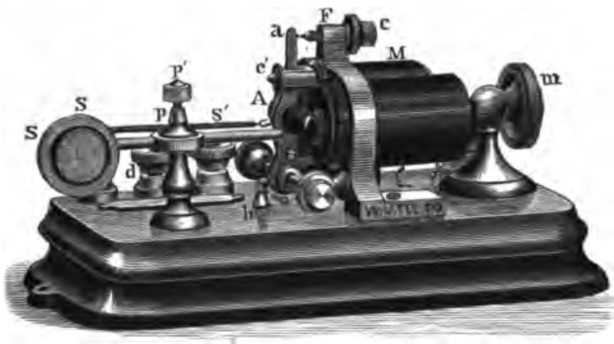


Fig. 232.

puts a secondary or local battery in connection with the receiving apparatus. Fig. 232 represents the pattern used by the Western Union Telegraph Company. The electro-magnet M is composed of two soft iron cores, each 2 inches long and $\frac{11}{32}$ of an inch diameter, which are screwed into a soft iron yoke or back armature, 2 inches long and $\frac{1}{4}$ inch in thickness. The helices are wound with about 1820 feet of No. 32 insulated copper wire, 0.009 inches in diameter, to a diameter of 1.25 inches. The average number of convolutions is 8,500, and the resistance 150 ohms. The electro-magnet is supported in front by a vertical

brass frame F, the foot of which is firmly secured to the mahogany base by screws from beneath. This frame has two circular openings, of a size just sufficient to allow the helices of the electro-magnet M to pass freely through them, without being fastened in any way. The rear end of the magnet is supported by a right and left screw, passing through and supported by a brass pillar secured to the base. The screw is capable of being turned by a milled head *m*, which gives the electro-magnet an advance and retrograde movement through a short distance in a horizontal direction, the object of which will be seen hereafter. In front of the poles of the magnet is the semi-cylindrical armature A, of soft iron, attached to the upright armature lever *a*, the lower end of which is mounted upon a steel arbor, turning between two adjustable set-screws, the latter being mounted upon standards projecting from the lower part of the frame F. The armature A, and its attached lever *a*, are capable of a movement to and fro upon its axis—in one direction from the attraction of the electro-magnet M, and in the other from the retractile force of the spiral spring *s'*. This movement is very slight, and is limited in one direction by the adjustable screw-stop *c*, and in the other by a fixed stop composed of an insulating material, and placed within the slotted projection *c'*, through which the lever *a* passes freely without touching anything but the stop referred to. The retracting spring *s'* is attached at one end to the lever A by means of a small hook, and at the other to a piece of strong thread, which is tied to a spindle, *s*, to which is attached a milled head, S. The spindle is mounted upon one end of a horizontal brass rod, which slides through a pillar, *p*, and may be fastened in any required position by a set-screw *p'*. The object of this arrangement is to render the tension of the spring *s'* adjustable, for reasons which will be referred to hereafter. It now remains to describe the electrical connections. At the back of the instrument are four brass terminals or binding screws, for the convenient attachment of wires. Two of these only are fully visible in the figure, one of the others being behind the milled head S, and the remaining one is almost entirely concealed by the electro-magnet M. The

insulated copper wires from the helices of the electro-magnet M are seen beneath it, coiled into loose spirals, and passing down through the wooden base, underneath which they are connected to the two right hand terminals, so that a current entering at one terminal passes directly through both helices of the electro-magnet, and thence to the other terminal. As we have before seen, the object of the relay is merely to break and close a local or secondary circuit whenever the main or primary circuit is broken and closed. In order to effect this, the armature lever *a* is insulated from the frame F by a bushing of hard rubber, which intervenes between the lever and the axis upon which it turns. A wire leads from the terminal *d*, underneath the base, to the screw-post *h*. A fine copper wire, above the base, connects the screw-post *h* with the armature lever *a*, to which latter it is fastened by means of a small screw seen in the figure just above the axis. When the armature is attracted by the electro-magnet a small platinum pin near the top of the lever *a* comes in contact with a corresponding platinum pin inserted in the point of the adjustable screw-stop *c*. The stop *c* is in electrical connection with the brass frame F, and this is in turn connected with the extreme left hand terminal by a wire passing underneath the base. Thus it will be readily understood that whenever the two platinum points are brought in contact by the forward movement of the armature lever, resulting from the attraction of the electro-magnet, a connection will be formed between the two last mentioned terminals, and the circuit connected with them will be closed.

The adjustments of the relay are of two kinds—1st, the adjustment of the extent of to and fro movement of the armature; 2d, the adjustment of the opposing action of the electro-magnet and of the retracting spring upon the armature.

The first mentioned adjustment is effected by the screw-stop *c*, which is movable, the other stop *c′* being fixed. The play between the platinum points or pins should never exceed one thirty-second of an inch, and when the movement of the lever is very feeble it should be made as small as possible. This adjustment, under ordinary circumstances, rarely requires alteration. The second

adjustment necessitates considerable skill and judgment on the part of the operator. When the action of the electro-magnet is very strong, and the armature does not fall off promptly when released, the tension of the spring must be increased by turning the milled head S. In some cases this increased tension will not be sufficient, and the remedy then is to lessen the action of the electro-magnet upon the armature, by removing the former to a greater distance from the latter, which is accomplished by turning the screw *m*. Care must be taken never to wind the spring S′ around the spindle *s*. Where there is danger of this the spindle should be removed to a greater distance from the armature by loosening the screw *p*′ and sliding the rod upon

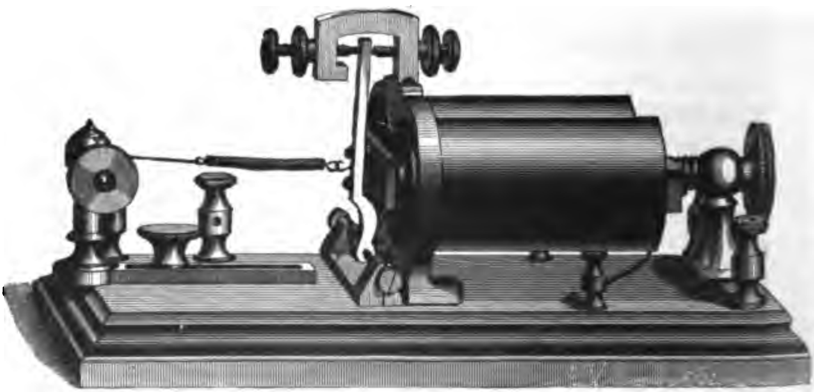


Fig. 233.

which it is mounted through the post *p*. Particular care should be taken that the fine wire connecting the screw post *h* with the lever *a* is not broken; a point which is somewhat liable to be overlooked.

Fig. 233 is another pattern of relay which is in very extensive use in the United States. It differs somewhat in form, though not in principle, from the one just described, and the different adjustments are made in substantially the same way.

THE KEY.

The Morse key is shown in fig. 234, in the form now used by the Western Union Telegraph Company. It consists of a curved

brass lever, A, four or five inches in length, fixed upon a steel arbor, G, which turns between adjustable set-screws, D D. The slight vertical movement upon its axis of which the lever is capable, is limited in one direction by the anvil C, and in the other by the adjustable set-screw F. One wire of the main circuit is connected to the metallic frame or base M of the key, and the other to the anvil C, which is insulated from the frame. These connections are made by means of the screws L L, which pass down through the table, and to which the wires are attached by being bent into eyes which are clamped between the nuts K K and the under side of the table. The lever A is provided with a knob or button, B, composed of some insulating material, by means of which it is pressed down at pleasure by the finger

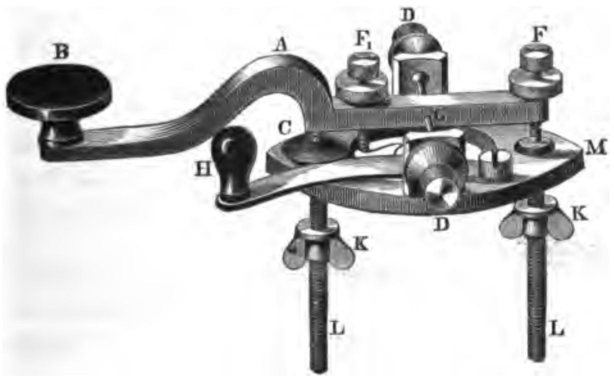


Fig. 234.

of the operator, bringing a platinum stud on the under side of the lever into contact with another similar one in the centre of the anvil C. By this means the circuit is closed precisely as if the wires themselves had been brought into contact with each other. The reason for making the contact studs of platinum is, that the infusible properties of this metal prevent it from oxidation by the electric spark which passes whenever the circuit is broken. When the pressure of the finger is withdrawn a spring beneath the lever restores it to its normal position. The upward pressure of this spring is adjusted by means of the set-screw F_1.

When the key is not in use, it is necessary to complete the circuit by closing the switch H, which is shoved into a recess between the anvil C and the frame M, thus forming an electrical connection from one to the other.

THE CLOSED CIRCUIT SYSTEM.

We have already stated (page 428) that the closed circuit system was adopted for working the American lines at a very early period. It is still in almost universal use throughout the entire telegraphic system of the United States and Canada. Fig. 225, the arrangement first used by Morse between Baltimore and Washington, represents the closed circuit in its simplest form. It includes two terminal stations, A and B, and a single main battery, E. The keys at each station are provided with circuit closers, as above described, so that the connection remains unbroken when neither station is transmitting. In the normal condition of the line a constant current flows from the + pole of the battery E through the wire *e* to the key P, thence through the wire *d*. to the relay R, thence over the line to the other station, passing through the relay and key, and finally to the earth at G_1. The circuit is completed, as explained in Chapter XXVIII, by means of a wire connecting the — pole of the battery E with the earth plate G. This constant circuit causes the electro-magnets of both the relays to attract their armatures, and these in turn keep the local circuits of the registers or sounders likewise closed.

When the operator at one station wishes to transmit a communication to the other, he opens the switch of his key, interrupting the flow of the current. This causes the armatures of both relays, and consequently of both registers, to fall off. If he now manipulates his key, by closing and breaking the circuit so as to form the characters of the telegraphic alphabet, the armatures of both his own and the distant relay, as well as those of the registers or sounders connected with them, will respond to every movement of his key, and consequently the communication may be written by the register, or copied from the sounder at

the distant station. As the sending operator's own instrument also responds to the movements of his key, it is evident that the receiving operator may interrupt him at any time by opening his key and thus breaking the circuit. The sending operator is instantly notified of the interruption by the failure of his instrument to respond to the movements made by his own key.

A number of stations, each provided with a set of apparatus consisting of a key, relay, register or sounder and local battery, may be placed in the same main circuit, only one main battery being required to furnish a working current for the whole number of relays. This is the arrangement adopted in practice, differing only from that shown in fig. 225 in that the main battery is usually divided, half of it being placed at each terminal station, for reasons which will be hereafter explained. As many as forty intermediate stations are sometimes operated in this manner, although it is seldom advantageous to attempt to work more than twenty or twenty-five instruments in the same circuit.

ARRANGEMENT OF APPARATUS AT A WAY STATION.

The simplest combination of apparatus in general use is that employed at a way station having but a single main wire, and one set of instruments consisting of a sounder or register, relay, key, local battery, switch and connections. The manner in which the different parts of the apparatus are arranged and connected with each other and with the line is illustrated in fig. 235, which represents a way station complete. The two terminal stations of the line are also shown in outline, for convenience of explanation.

The sounder, relay and key are usually most conveniently arranged upon a table T, from three to four feet in length and about two feet in breadth. The sounder, or its substitute the register, should be placed nearly or quite in the centre of the length of the table, the key K being on the right, and the relay R on the left, as shown in the diagram. The switch C is usually

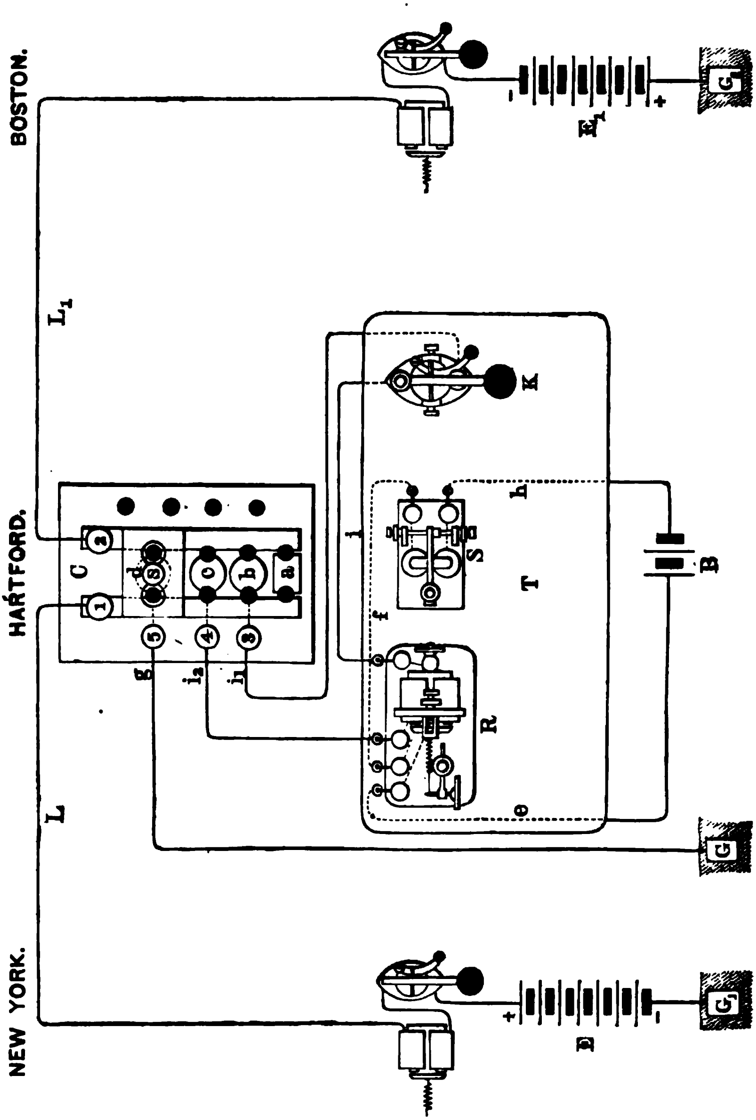


Fig. 235.

placed upon the wall, in an upright position, in any convenient location. The object of the latter apparatus is to facilitate the making of the necessary changes in the connections of the wires, and this is effected by means of the same device as that used in the rheostat (figs. 116 and 117), viz., metallic pegs with insulating handles, which may be inserted between two thick plates of brass, thereby forming an electrical connection from one of them to the other.

If we suppose that the way station in the diagram represents Hartford, and the two terminal stations New York and Boston, respectively, L will represent the line wire from New York to Hartford, and L_1 the line wire from Hartford to Boston. These line wires are extended into the way station by means of insulated copper leading-in wires, which are connected with the binding screws 1 and 2 of the switch C, these being attached to two upright metallic bars, secured to the wooden base-board and extending to the peg holes 12 and 13. One of the instrument wires i_1 leads from the binding screw 3 of the switch to one of the screws of the key K, underneath the table; from the other screw of the key a wire i goes to the first right hand main terminal of the relay R. The other instrument wire i_2 leads from the binding screw 4 of the switch to the second right hand terminal of the relay; a wire g leads from the binding screw 5 of the switch to the earth at G. Between the two upright metallic bars of the switch C are placed three metallic discs, b, c, d, which are electrically connected with the three binding screws, 3, 4, 5, by means of wires passing underneath the base-board. Upon the disc c is mounted a rectangular flat metallic plate d, extending over the upright bars on each side, but not quite touching them, the space between being about the thickness of a piece of paper. This constitutes the lightning arrester, and will be more particularly referred to hereafter. The various numbers, from 6 to 13 inclusive, represent the holes provided for the insertion of pegs for making the various connections in the main circuit, while 14, 15, 16 and 17 are for holding pegs which are not in use.

The wires of the local or office circuit are run as follows: from the local battery B the wire *e* runs to the first left hand (local) terminal of relay R; the wire *f* runs from the second left hand (local) terminal of the relay to one terminal of the sounder or register S; and finally the wire *h* runs from the remaining terminal of the sounder or register to the other pole of the local battery B. It is immaterial in this case which pole of the local is connected to the relay and which to the sounder.

The various changes which may be made upon the switch C for different purposes are as follows:

1. *To cut out the apparatus.*—Insert pegs in holes 12 and 13, leaving 6, 7, 8, 9, 10 and 11 open. The main line current now passes from the + pole of the main battery E, at New York, through the instruments at that station, and thence over the line L to 1, and through 12, *a*, and 13 of the switch to 2, thence over the line L_1, and through the apparatus at Boston to the — pole of the main battery E_1, at that place, and thence to the earth at G_2. The — pole of the New York battery E is also connected with the earth at G_1, and therefore the circuit is completed by the earth. When thus arranged, it will be seen that the ground wire *g*, and also the instrument wires i_1 and i_2 at the way station, are entirely disconnected from the main line.

This is the manner in which the pegs of the switch should always be arranged when leaving the office or during a thunder storm.

In some of the switches in use the cut-out plate *a* is omitted. When this is the case, the holes 10 and 11 should be pegged, and the remaining ones left open. The key K should also be opened, which serves to disconnect the wire i_1, i_2 being open at the switch. This prevents all possibility of lightning injuring the instruments during the absence of the operator. In cutting out by means of one of the instrument wires, the one which runs to the key should always be made use of, not the one going to the relay.

2. *To cut in the apparatus.*—Insert pegs in 8 and 11, or else in 9 and 10 (it is immaterial which, though the former is most

usual), and remove the pegs from 12 and 13, taking care that the remainder of the holes are also open. If possible, it is always better to peg the holes 8 and 11, or 9 and 10, before taking out 12 and 13, which can be easily done if four pegs are provided, as then the circuit of the main line is not interrupted even for an instant. Care should be always taken before cutting in the instruments to see that the switch of the key K is closed.

If Nos. 10 and 11 are used for cutting out, close the key K, insert a peg at 8, and afterwards remove the one from 10.

3. *To ground the line, or put on a ground.*—In case the line is broken, or the circuit open, as it is termed, it becomes necessary for the way station to test the circuit. This is done by grounding the line, as follows: Suppose the line broken at some unknown point. Hartford already has pegs in the holes 8 and 11, as in the ordinary manner of working, but of course perceives no current. One of the spare pegs is placed in No. 6, the effect of which is to connect the end of the New York line L with the earth wire *g*. This completes the circuit of the New York battery, but it produces no effect on the Hartford instrument, as the current does not pass through it. The peg is then removed from 6 and placed in 7. The circuit of the New York battery is again completed as before, except that it now includes the Hartford instruments, its course being from the line wire L through 1, 8 and 4, thence through the instruments as usual, and back to 3 and 11, and from thence through the peg 7 to the screw 5 and wire *g*, and finally to the earth at G_1. Hartford now becomes a terminal station, working with New York by means of the battery E at the latter place, the arrangement in fact being precisely the same as that shown in fig. 225.

This operation demonstrates to the operator at Hartford that the break is between that place and Boston. If, on the contrary, the circuit had been completed through the relay by the insertion of the peg in 6, it would have shown the fault to have been located in the opposite direction.

It sometimes occurs that the circuit cannot be completed on either side, and the line therefore appears to be interrupted in

both directions. In that case the defect is very probably within the limits of the station itself, usually somewhere about the instrument connections, which should be carefully examined.

If the operator at a way office finds by the above test that the line is interrupted in a particular direction, it is his duty to report the circumstance at once to the terminal station in the opposite direction, from which he will receive instructions in regard to his proper method of procedure, in order to allow the uninjured portion of the line to be operated until the difficulty is removed.

Fig. 236.

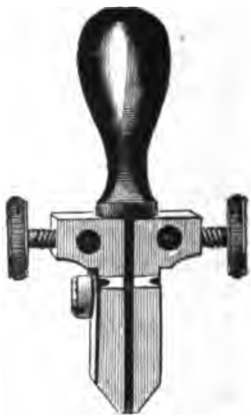


Fig. 237.

It is important that the pegs should always be crowded firmly into the holes with a twisting motion, in order to insure a proper connection being made.

The arrangement shown in fig. 236 is often used at way stations instead of the one last described. It is termed a plug, or more properly, a wedge cut-out. The instrument wires i_1, and i_2 of fig. 235 are screwed into the opposite sides of a wedge, as it is technically termed, which is shown of full size in fig. 237. It

consists of two pieces of brass, insulated from each other by means of a thin plate of hard rubber, as shown in the figure, and provided with a handle of the same material. The two ends of the line wire are connected with the two binding screws at the top of the base board (fig. 236). The right hand binding screw is connected, by means of a wire underneath the base board, with an elastic strip of brass. The upper end of this strip is rigidly attached to the board, while the lower end is armed with a brass pin, which, by the elasticity of the strip, is pressed firmly against another pin, also screwed to the board. The stationary pin is attached by means of a wire to the other binding screw, and is thus placed in connection with the line wire. This device is termed a spring-jack. When the wedge carrying the instrument wires is pressed in between the two pins it separates them, breaking the circuit of the main line, but at the same instant opening a new path for the current through the two sides of the wedge and the instruments. Thus the latter may be inserted into or withdrawn from the main circuit without interrupting it, by a single almost instantaneous movement. For many places this is an exceedingly simple and effective arrangement. It is sometimes used for large stations in combination with the peg-switch, as will be hereafter shown. The wedge cut-out is frequently provided with a lightning arrester and ground wire connection, which is arranged with pegs in much the same manner as the switch in fig. 226.

In placing the apparatus at a way station, the local battery should be set in a warm and dry location, not too far from the instrument—preferably in a box or on the shelf of a closet, where it is convenient of access. An embossing register should always be placed so that the paper will pass from right to left in front of a window, and at right angles to the direction of the light which enters it, otherwise the embossed characters cannot be read without considerable difficulty.

It very often happens that a number of different lines traversing the country in the same direction or in different directions pass through the same way station. In some of these

cases the necessities of the service require that there should be a separate set of apparatus provided for each line, but it is more frequently the case that a smaller number of instruments is sufficient, provided means are furnished by which any one of the instruments can be inserted into the circuit of any required line at pleasure. The simplest way of providing for this is to make use of a number of spring-jacks (fig. 227) corresponding to the number of line wires, and placed side by side upon the same base-board. The wires from each separate set of instruments terminate in a wedge (fig. 228), and by this means any instrument may be placed in connection with any required line wire at a moment's notice, simply by inserting its wedge into the corresponding spring-jack.

This arrangement, however, makes no suitable provision for interchanging the line wires among themselves—a proceeding which often becomes necessary, for instance, when two or more lines running in the same general direction are each interrupted, but at different points. By connecting the uninjured portions of different lines with each other, it is often possible to arrange one or more complete circuits for the transaction of business. The wires are interchanged or cross-connected, as it is termed, at the different way stations, in accordance with instructions given by the person in charge of the circuits at one of the terminal stations.

In order to conveniently accomplish this, the different wires are brought into the same switch at each of the principal way stations, and the necessary changes are made upon it without any interference with the lines themselves.

There are many different varieties of switches, but they are all constructed upon the same general principle. This will be readily understood by reference to fig. 238, which represents a switch for a way station having two line wires running east and west, and distinguished according to custom as numbers 1 and 2, and two instruments designated as A and B. The details of the construction are the same as in fig. 235. It remains to be shown how the various changes are made, other than those

which have already been explained in connection with the single wire switch.

1. *Both lines connected straight, with both instruments in.*—Insert pegs in 5, 10, 15 and 20, leaving the remaining holes open.

2. *Lines cross-connected or interchanged.*—In this case it is required to connect No. 1 wire west with No. 2 wire east, and No. 1 east with No. 2 west. Insert pegs in 5, 12, 14 and 19, leaving the others open. In this case both instruments A and

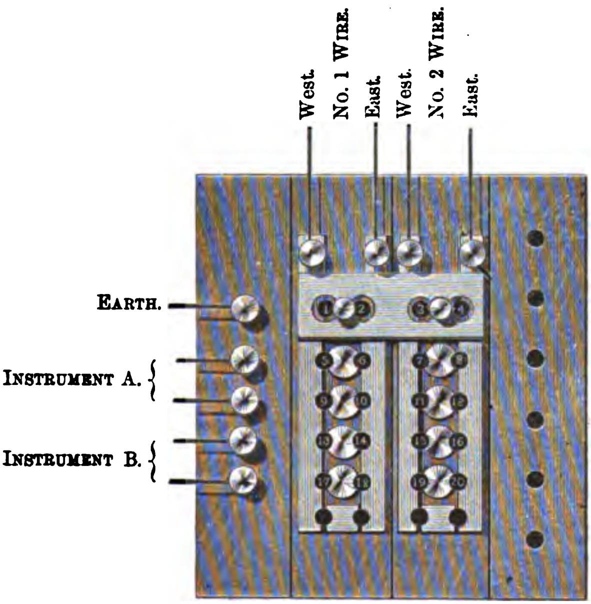


Fig. 238.

B are included in the circuit. If it is desired to leave instrument A out of the circuit, the peg should be changed from 12 to 8. In the same manner instrument B is cut out by changing the peg from 19 to 15.

3. *Lines grounded or put to earth.*—This may be done on either wire, east or west, by inserting pegs in 1, 2, 3 or 4, as required, as in the single wire switch.

4. *Lines looped.*—It is sometimes required to loop two wires, as it is termed, for making tests and other purposes. To loop numbers 1 and 2 west, with an instrument in circuit, insert pegs in 5 and 11; without an instrument, insert pegs in 5 and 7. Numbers 1 and 2 east may be looped in the same manner.

This explanation sufficiently illustrates the principle upon which the switch is manipulated. Switches are made to accommodate almost any required number of wires, but the principle is the same as in fig. 238.

Fig. 239.

Another mode of constructing switches sometimes employed is shown in fig. 239. Two sets of brass bars are arranged at right angles to each other and on opposite sides of a wooden frame. The connection is made at any desired point by means of a metallic peg, provided with a spiral spring, which, when the peg is inserted and secured in its place, presses against the two bars, forming an excellent connection. The manipulation is the same as in fig. 238. There are also several other arrangements which are more or less used, but they differ from those which have been described merely in the device by which the connection is made. None of them are regarded as being so simple, compact and efficient as the peg switch, which we have selected as an illustration of the principle of all.

ARRANGEMENT OF APPARATUS AT A TERMINAL STATION.

The simplest arrangement of the wires at a terminal station is the one shown in fig. 225, but it is seldom that such a station does not contain more than one line wire. Any greater number of lines entering a terminal station renders it desirable to make use of a switch similar in construction to that shown in fig. 238, but with its connections somewhat differently arranged, for in the case of a terminal station, provision must be made for connecting and disconnecting the main batteries as well as the instruments.

Fig. 240 represents a section of the switch in the New York office of the Western Union Telegraph Company, which will serve to illustrate the arrangement employed in other large American stations. In this arrangement both the peg-switch and the wedge cut-out are employed.

The New York switch is divided into seven sections, each section accommodating a certain portion of the lines entering the office. The wires are distributed according to the geographical location of the portion of the country with which they connect. The lines running eastward, for example, are placed in one section of the switch, and those running northward in another, while still another section accommodates the local or metropolitan wires, etc., etc.

The section represented in the figure is provided with 44 vertical bars, to the lower end of which the line wires are connected. Between each pair of upright bars is placed a row of metallic discs, to which the batteries are connected. All the discs in each separate horizontal row are connected together at the back of the base board by means of a horizontal copper wire, the extreme left-hand disc having a distinguishing number engraved upon it. The vertical bars may be connected with the horizontal discs at any required point by the insertion of a peg G at the point of intersection. Immediately underneath the lower end of the vertical bars are placed a corresponding number of spring-jacks, and beneath these again still another

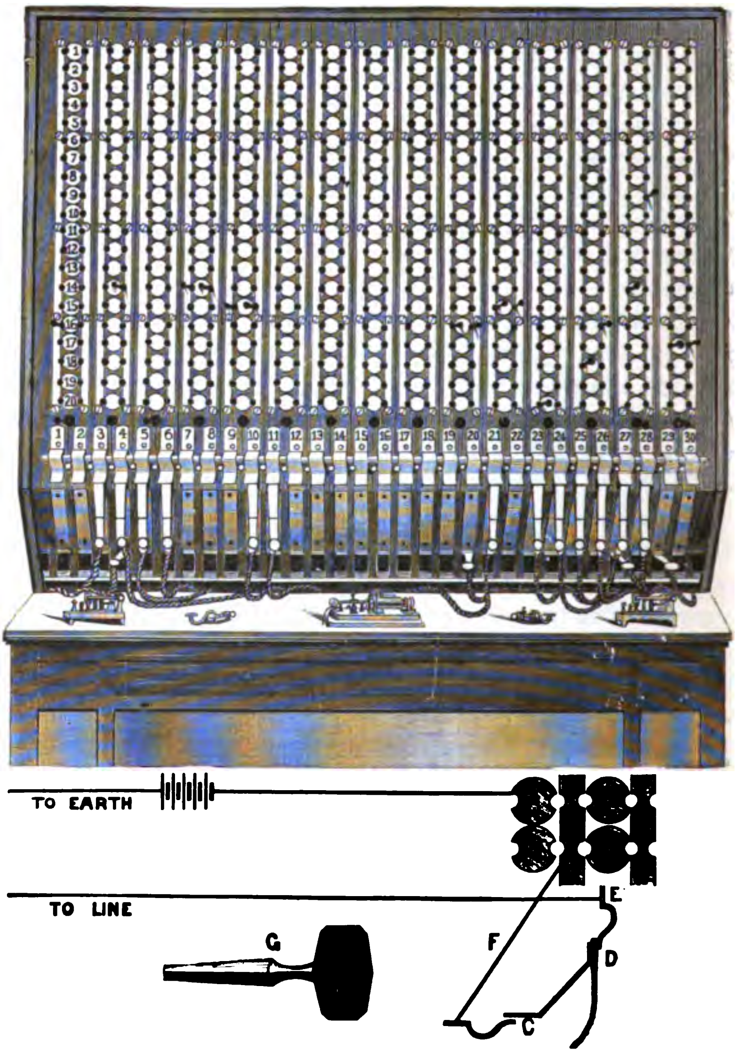


Fig. 240

series of spring-jacks. Each main wire coming in from outside passes first through one of the upper spring-jacks, then through the lower one corresponding to it, and thence to its appropriate vertical bar. Each spring-jack bears an ivory plate, upon which is engraved the number of the circuit to which it is attached.

The diagram beneath the table upon which the switch rests shows how the connections are made. In this diagram the positive pole of the main battery is represented as being connected with the button A; a wire in the rear connecting A with A′. The main line wire is represented in the diagram as connecting with E, which is the upper spring-jack referred to. At D is inserted a wedge connecting by means of insulated wires with the apparatus. At C the lower spring-jack is represented, in which is to be inserted, when necessary, the special batteries or loops. The wire F connects the lower spring-jack with the vertical metallic strip 1, and by inserting the peg G in the circular orifice between the button A and the strip 1, the line wire is connected through the battery to earth.

Each section of the switch is built of mahogany, cut in strips two inches wide by one inch thick, which are separated from each other by a space of one eighth of an inch, to prevent injury to the brass work by shrinkage. Each piece of mahogany supports two strips of brass and one row of discs or buttons. The spring-jacks are held in position by stout spiral wire springs attached to the back of the switch. One row of horizontal discs is connected directly with the earth. The lightning arresters are not attached to the switch, as in the smaller stations, but are placed at the point where the lines first enter the building.

The instruments seen upon the shelf or counter in front of the switch are employed by the chief operators for testing purposes, etc. They are provided with wedges, so that they can be thrown into the circuit of any required line at a moment's notice.

In New York, as in most other large stations, the different sets of apparatus are placed in groups of four, upon tables about four feet by six, which are divided by means of two vertical

intersecting screens into four sections, each section accommodating a complete set of instruments, sounder, relay and key. The screens are composed of plate glass. A group of four pairs of instrument wires extends from the switch to each table, and a second group of four pairs of local wires extends from each table to a group of four distinct local batteries in the battery

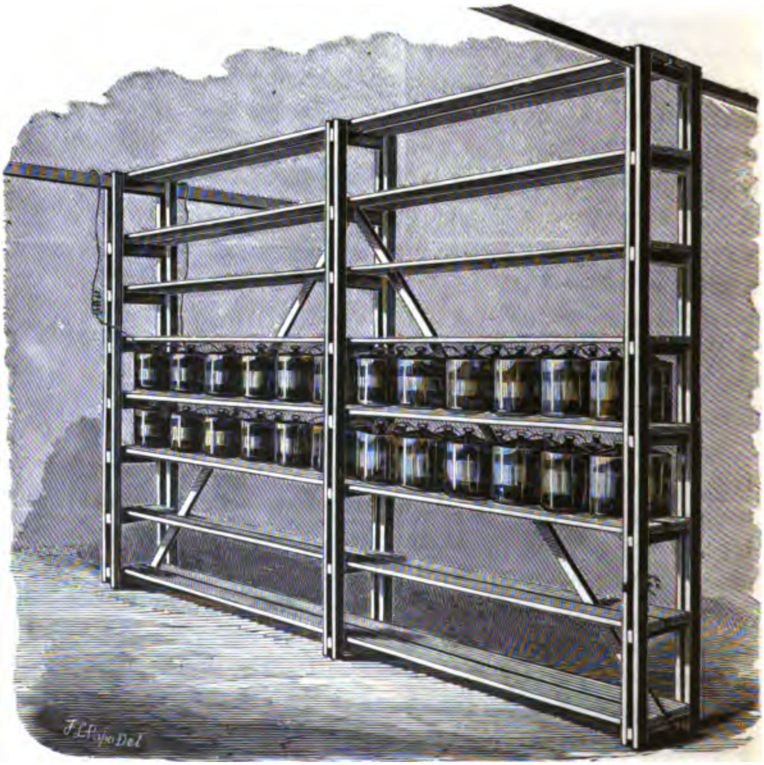


Fig. 241.

room. The wires are insulated with a double coating of gutta percha and are then laid up in cables and bound with tarred tape.

It was formerly the practice to group a number of local circuits together, using a common return wire for the whole

group, but experience has shown that this arrangement is objectionable, and that it is better to keep all the circuits, main and local, of each line, distinct from those of other lines in the same station.

Fig. 241 shows the manner in which the battery stands are constructed and the batteries arranged upon them in the battery room of the general telegraph station of the Western Union Telegraph Company in New York. Each stand is provided with eight double shelves, capable of containing 24 cells each, of gravity battery, or 192 cells in all. The plan of construction and manner in which the diagonal braces are inserted in order to strengthen the structure are clearly shown in the figure, and require no detailed description. The stand occupies a space about eight feet long and eighteen inches wide by seven feet six inches in height. The top shelves of each stand are usually reserved for the local batteries. The battery room is directly underneath the operating room, and each local battery is placed as close as practicable to the instrument with which it is connected.

At the present day many of the Morse instruments in the principal offices are arranged to be worked on the duplex and quadruplex systems as well as in the ordinary manner. The description of these improved methods of transmission will be given in a separate chapter in another part of this work.

THE REPEATER OR TRANSLATOR.

During the early experiments of Morse, in 1836-37, one of the most important practical considerations which necessarily presented itself, was the limit of distance through which an electric current could be made to induce sufficient attractive power in an electro-magnet to move a lever. He is said to have frequently remarked, that if he could succeed in working a magnet ten miles he could go round the globe. "Suppose," said Morse, "that in experimenting on twenty miles of wire we should find that the power of magnetism is so feeble that it will but move a lever with certainty a hair's breadth; that would be insufficient,

it may be, to write or print, yet it would be sufficient to close and break another or a second circuit twenty miles further, and this second circuit could be made, in the same manner, to break and close a third circuit twenty miles further, and so on round the globe."

In these words we have a concise explanation of the general principle of the apparatus now known as the repeater or translator. When, in 1844, Morse applied this idea for the first time to a circuit of any considerable length, he modified it materially, so that it assumed the form which we have already explained in connection with fig. 225, viz., the relay and local circuit. It was soon found by experience, that provided the electro-magnets and batteries were properly proportioned to each other, the length of line through which a relay could be made to open and close a local circuit, so far from being limited to twenty miles, was not less than four or five hundred miles, under favorable circumstances—a distance more than sufficient to meet the commercial requirements of telegraphy at that early day.

In September, 1846, the arrangement now known as the button repeater was put in operation for the first time at Auburn, N. Y., for the purpose of repeating press news over a branch line from that place to Ithaca. The armature levers of the registers on both lines were provided with platinum contact points precisely like a relay, and the lever on each register formed in effect a key for opening and closing the circuit of the other line. A simple double-acting switch or button was arranged so that a connection could be formed between the repeating contact points of either instrument at pleasure. Thus the operator, by merely changing the position of the switch, could cause the signals on one line to be transferred to the other, and *vice versa*, at pleasure.

The first attempt to telegraph direct over long distances was made upon the line between New York and New Orleans, by means of a peculiar arrangement of circuits and automatic repeaters invented by C. S. Bulkley in 1848. The diagram, fig. 242, represents the apparatus at one of the repeating stations

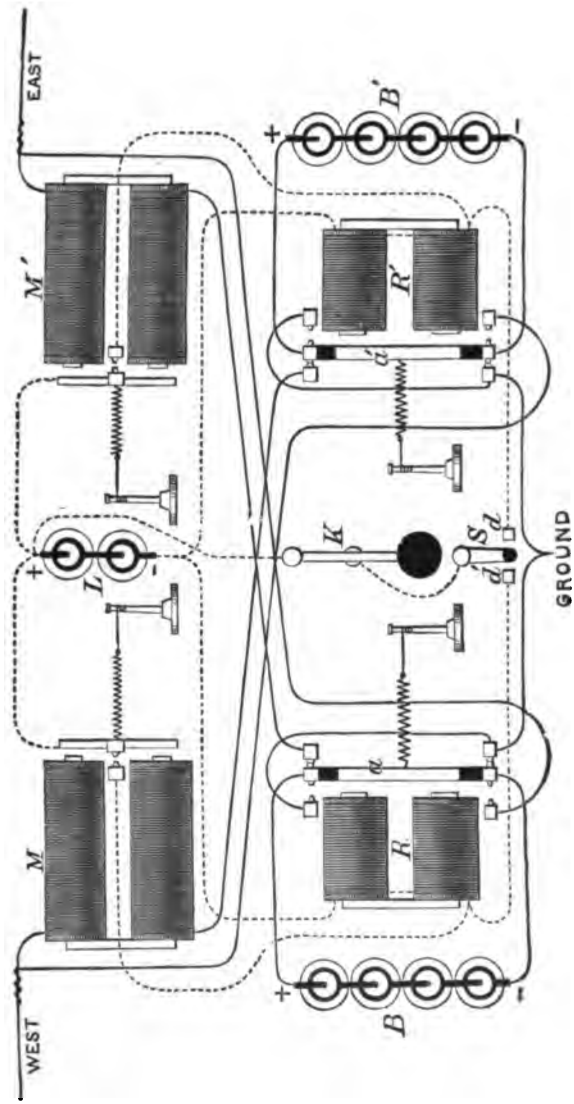


Fig. **242.**

in its normal position, when the line is not in use. R and R′ are two electro-magnets, the armatures of which act as pole-changers for the main batteries B and B′. Thus, when the magnet R attracts its armature *a*, the poles of the main battery B, belonging to the eastern line, are interchanged or reversed in respect to the line. The normal position of the main batteries at each end of the line is with their like poles opposed to each other, and under these conditions there is of course no current manifested in the line. Now, if the operator at the distant end of the eastern line operates his pole-changer, thereby reversing his main battery so that it coincides with that of battery B, a current traverses the eastern line, and the relay M′ attracts its armature, closing the circuit of the local battery L through the helices of the pole-changer magnet R′. This in turn reverses the main battery B′ with respect to the western line, and thus the same operation is repeated at the next transfer station west. The key K is placed in the local circuit, and by means of the switch S the operator at the station can work either the pole-changer R or R′ accordingly as he wishes to transmit in an easterly or westerly direction, and the action is transferred to the main circuit as before. It will be seen that the operation is entirely automatic in either direction.

The invention of an automatic repeater adapted for use upon the closed circuits ordinarily used upon the American lines proved to be a somewhat difficult matter. The first success in this direction was attained by Messrs. Farmer and Woodman, in 1856. In this repeater (fig. 243) a simple latch or hook is employed to prevent the circuit on which the transmitting operator is working from being broken by the action of the repeating lever belonging to the other circuit. In the figure the eastern and western main circuits are both represented as closed. The sounders R R′ are operated by local circuits from the relays M M′ in the usual manner, but these have been omitted in the figure to avoid confusion of lines. The eastern main circuit enters at the right, passing through the relay M′ to the flat spring *f*, contact point P and main battery or earth at G. The

western main circuit is similarly connected on the other side. If the flat spring f be lifted from the point P, the eastern main circuit will be broken, and the arrangement on the other side is the same. At the rear end of the armature lever L of the sounder R a detent or latch d is suspended from a shaft a, to which is also rigidly attached the arm c, the extremity of which projects beneath the end of another arm, l', fixed upon the lever L′ of the sounder R′ of the opposite side. The detent, shaft and arm are retained in the position shown by means of a delicate spiral spring, s. The opposite side of the apparatus is arranged in precisely the same manner. By an inspection of the diagram it will be observed, that on the side where the main circuit is first broken, the movement of the sounder lever throws

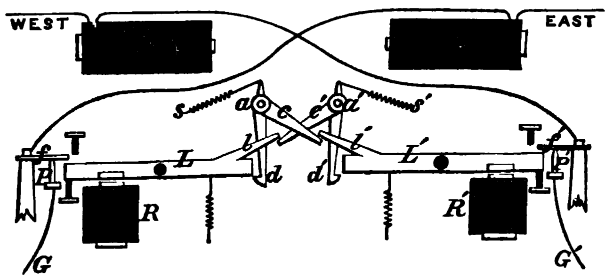


Fig. 243.

a detent under the other one before opening the circuit connected with it; and when the circuit is to be closed, instead of relying upon the prompt movement of the relay to prevent a false break, the sounder lever is held in position by the detent until the relay has actually closed the local circuit of its own sounder. When this has been accomplished the sounder lever is lifted from the detent and the spring draws the latter back to its original position. The object of the flat springs f and f' is to prevent the opposite circuit from being broken until the sounder lever has been locked by the detent, but the device incidentally serves another very important purpose, as it prevents in a great measure the shortening of the signals which would otherwise take place in the transmission from one circuit to the other, and

which formed a serious defect in Bulkley's repeater, especially when the signals passed through a number of them in succession.

The principal defect in the practical operation of this repeater arises from the fact that the pressure of the armature lever L upon the latch *d* causes the detention of the latter until the relay magnet of the receiving circuit becomes sufficiently charged to draw its armature forward, which movement is followed, of course, by the closing of the local circuit and release of the latch. Therefore, any desirable tension of the relay spring cannot change the result in this respect. In breaking, however, the distant receiving station must open the circuit at the precise instant when the latch is free (or not under the extremity of the sounder lever), otherwise the object cannot be accomplished, although the circuit may be held open for an indefinite time.

Inasmuch as the proportion of time during which the sounder lever and latch are locked depends upon the relative tension of the relay spring on the receiving side, it follows that oftentimes great skill must be exercised by the distant receiving operator, in order to throw in a break at the right moment.

The custom was, in the use of this repeater, to make a succession of dots, until one of the intervening breaks chanced to make a hit, but the loss of time and uncertainty in this respect caused the abandonment of the system.

In 1858 Mr. George B. Hicks patented a very ingenious automatic repeater, which is, in fact, a button repeater with a self-acting button or circuit changer. It is shown in fig. 244. The apparatus consists of two relay magnets M and M′, two sounders S and S′, operated by means of local batteries B and B′ in the usual manner, and an automatic circuit changer *l*, actuated by two local magnets L L′. The main circuit of each line, east and west, is opened and closed directly by the lever of the relay of the other line, instead of through the agency of the sounders, as in Farmer and Woodman's plan. The eastern main circuit enters at E, passes through the repeating points *e f* of the opposite relay, and thence to the earth at G. The western main circuit pursues a similar course from W to G′. In the drawing the circuits of

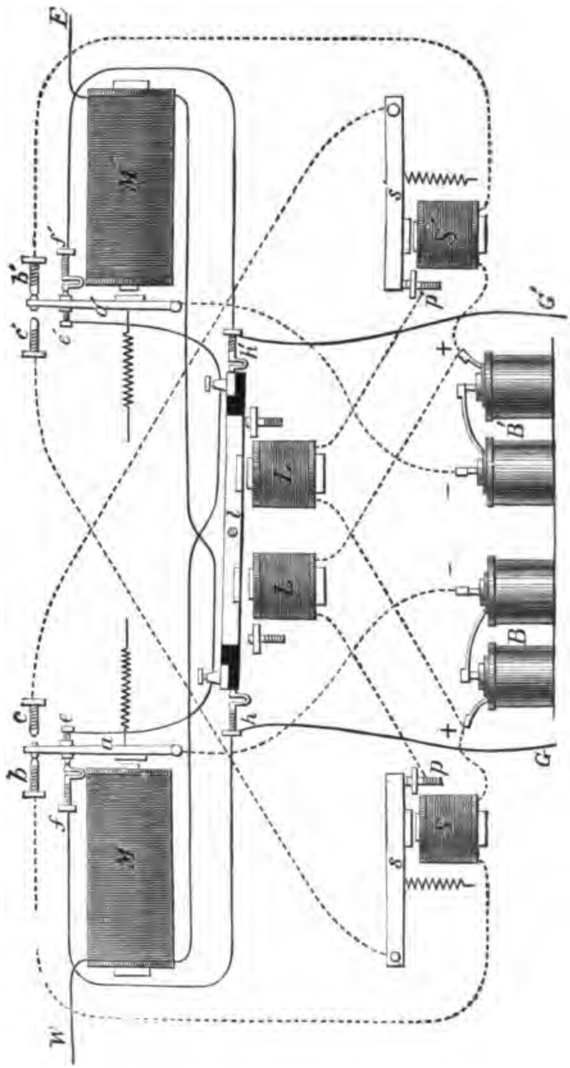


Fig. 244.

both main lines are closed, and so also are the local circuits of the sounders S S′, while the circuit changer *l* is in the position it assumes when the operator on the western line is transmitting, the spring contact, *h′*, forming a short circuit between the repeating contact points *e′* and *f′*.

Suppose, now, that the eastern operator wishes to transmit to the west. Upon the opening of his key the armature of the relay M′ is released, breaking the local circuit of the sounder S′ at *b′*, and immediately afterward closing upon its back contact stop *c′* the local circuit through the switch magnet L. The circuit changer or switch *l* being hung in the centre, responds to the attraction of either the magnet L or L′ separately. The local circuit of the switch magnet L may be traced by the dotted line from *c′* through *s*, *p* and L to the local battery B′, and thence back to the armature lever *a′*. The magnet L attracts the left hand end of the circuit changer *l*, and the contact spring *h*, which had been pressing against the insulating piece of hard rubber, forms a connection with the insulated metallic plate above it, upon the end of the lever *l*, thus changing the course of the eastern main line directly to the ground by the wire G, instead of passing through *e*, *f* and *h*, while precisely the reverse operation takes place at the other end of the circuit changer *l*, and the eastern relay breaks and closes the circuit of the western line at *e′ f′*. The main batteries are usually placed between the springs *h h′* and the earth at G and G′.

About a year after the above apparatus was patented by Hicks, another automatic repeater, upon a new principle, was invented by Mr. James J. Clark. He made use of an additional local magnet for essentially the same purpose as the detent of Farmer and Woodman's apparatus. Fig. 245 shows the arrangement of the parts. The western main line W passes through the relay magnet M, thence to the flat spring *f′*, contact point *s′*, and finally to the main battery or earth at G. The eastern main line E is connected in the same manner through the corresponding parts on the opposide side of the apparatus. The springs *f f′* are insulated from the sounder levers *l l′* by

small pieces of hard rubber. The arrangement of the ordinary local circuits needs no explanation. The wires are omitted in the figure to avoid confusion. The levers *a a′* of the relays M

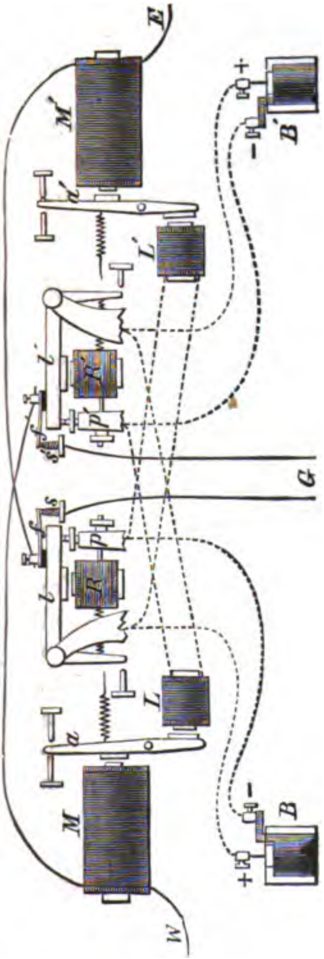


Fig. 245.

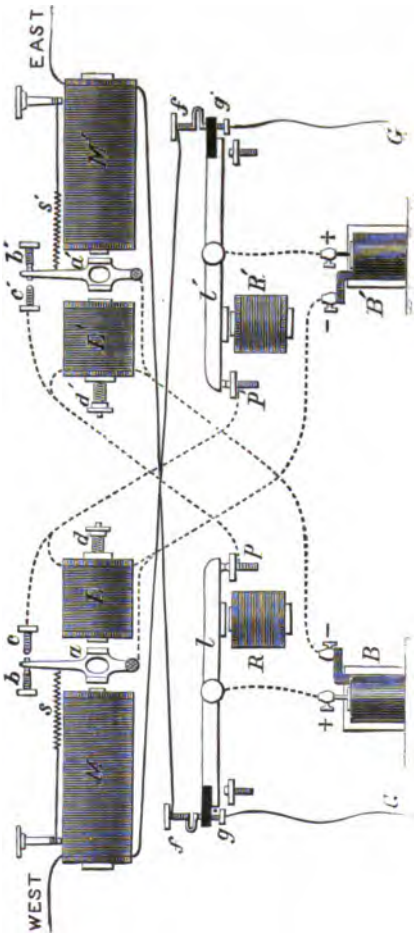


Fig. 246.

M′ are prolonged a short distance below their fulcrums, and local magnets L L′ are so placed as to act upon armatures at the lower

end of each lever, as clearly shown in the figure. It will be apparent that the action of these local magnets upon the levers will be the same as that of the relay magnets M M′. By tracing the circuit from the additional or extra local battery B, it will be seen that it is so arranged that the closing stroke of the sounder R diverts the current from the local magnet L′ by forming a shunt of no appreciable resistance by the way of *l* and *p′*. The other local battery B′ is connected in the same way. The mode of operation of the apparatus is obvious. When the circuit is broken on either side, the sounder lever rises and throws the local current through the holding magnet of the opposite relay before breaking the opposite main circuit, and thus the relay in the second circuit is prevented from interrupting the operator of the first circuit.

A magnetic adjusting repeater was patented in 1862 by Mr. Hicks, in which the auxiliary local batteries and magnets of Mr. Clark were made use of, but were quite differently arranged. The auxiliary magnets L L′ (fig. 246) were placed so as to act upon the armature levers of the relays M M′ in an opposite direction. These magnets are movable by means of adjusting screws *d d′*, and they are used in the place of a retracting spring for the purpose of adjusting the relay armatures *a a′*. The circuits of the auxiliary local batteries B B′, shown in dotted lines, pass through the sounder levers *l l′*, the contact points *p p′*, and thence to the auxiliary magnets L L′ on the opposite side of the apparatus. These magnets are adjusted at such a distance from the armatures *a a′* that their attraction is not sufficient to overcome that of the magnets M M′, unless the main circuit is broken. When this occurs, the armature lever on that side is drawn back against the contact point *c* or *c′*, as the case may be, by the action of the auxiliary magnet, which, however, shunts itself by this means whenever the armature lever touches the contact point. The magnetism in L being thus destroyed, the spring *s* tends to draw the armature forward again, but the forward movement breaks the shunt connection at *c*, and thus the magnetism in L is restored. The tension of the spring *s*

being but just sufficient to overcome the inertia of the lever *a*, and thus draw it away from the point *c* when there is no opposing force, the lever vibrates to and fro on this point through such a small space and with such rapidity that the armature is always ready to obey instantly the slightest impulse caused by the attraction of the relay magnet. The manner in which the apparatus operates will be readily understood. If the circuit is broken, for instance, on the western line, the armature *a* is released by the relay magnet M, and is drawn back by the attraction of L. This opens the local circuit of the sounder magnet R, which first breaks the auxiliary local circuit of the eastern relay at *p*, and then the eastern main circuit at *f g*. The armature of the eastern relay M′ does not, however, fall off when the main circuit is broken, being held in place by the tension of the spring s′, which is free to act, being no longer opposed by the attraction of L′. When the western main circuit is closed the operation is reversed.

Each of the repeaters which have thus far been described, has been used to a greater or less extent upon the telegraph lines in the United States. Each successive one, being in some respect an improvement over its predecessors, has partially or wholly superseded them, only to be in turn set aside in favor of some later and more perfect invention of the same kind. As we have seen, various devices have been applied to render the closed circuit repeater automatic in its action. These have been found to operate successfully, provided the lines be so nearly free from escape as to allow the armatures of the relay magnets on each side of the repeater to work in unison; but it becomes a more difficult matter in working very long circuits, or over escapes necessitating high relative tension of the relay springs.

The chief difficulty encountered by automatic repeaters is that of so arranging them as to continue a holding device in operation for such length of time, after the closing of the circuit by the sending operator, as will enable the relay itself to control and close its armature by attraction, thus providing against a false break upon its removal.

In consideration of the conditions under which repeaters are really valuable, this feature is of vital importance.

No false breaks can occur from this cause in the use of Farmer and Woodman's repeater, and from this fact the invention seemed for a time likely to prove a final solution of the repeater problem; but experience demonstrated that the means by which the desired object was attained introduced another difficulty, which rendered the repeater exceedingly difficult to operate, and which had the effect of preventing its general adoption. This defect has already been alluded to in the description of this repeater on page 464.

About the year 1864 a repeater was invented by Mr. G. F. Milliken, in which the defect to which we have referred, as being generally found in automatic repeaters, is entirely obviated, without the introduction of any feature detrimental to its operation in other respects, by a novel arrangement or application of the auxiliary local magnet first introduced by Clark, the armature lever of which, when drawn back by its spring against the lever of the relay with which it is placed in mechanical combination, prevents the movement of the latter, when the main circuit through the relay is broken. The adjustment of these auxiliary local magnets and of their armature springs being entirely independent from that of the relays, it is only necessary that such springs be actually and relatively stronger than those of the relays with which they are mechanically combined.

By this means false breaks, arising from any required tension of the relay spring on the receiving side of the repeater, are effectually prevented, as will be seen by the following description of its construction and operation:

Fig. 247 represents the apparatus employed and shows the connections between its parts, with the exception of those of the ordinary local circuits, to which reference is not here necessary, the relay on each side operating its sounder in the usual manner. The course of the auxiliary local circuits is shown by dotted lines. The auxiliary local magnet on each side is placed in a position opposite to the relay and at a convenient height, so that

its armature lever, when drawn back, may press against that of the relay, as shown in fig. 248.

R and R′ represent the relay or receiving magnets, placed in the main circuits, which connect the batteries and earth G′ and G through the repeating points *l*′ and *l* of the opposite sounders, respectively.

LM and LM′ are the local sounder magnets, each operated by the relay on the same side.

L and L′ are auxiliary local magnets, operated respectively by the movement of the opposite sounder levers H′ and H, as indicated by the dotted lines E and E′.

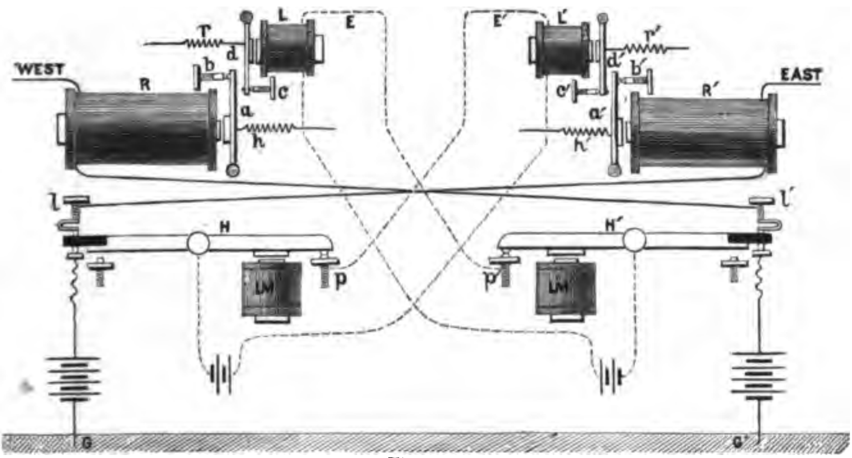


Fig. 247.

Now, if the western main circuit be broken at a distant station, the movement of the armature lever *a* of the relay R breaks the local circuit of the sounder LM at *b*, causing the sounder lever H to break the extra local circuit E′ at *p*, thus allowing the armature lever *d*′ to be drawn by the spring *r*′ against the extremity of the relay armature *a*′. The same movement of the sounder lever H also breaks, at substantially the same time, the eastern main circuit at *l*, but the lever *a*′ is prevented from being drawn back, and thereby causing a break in the western main circuit *l*, by the tension of the spring *r*′, which

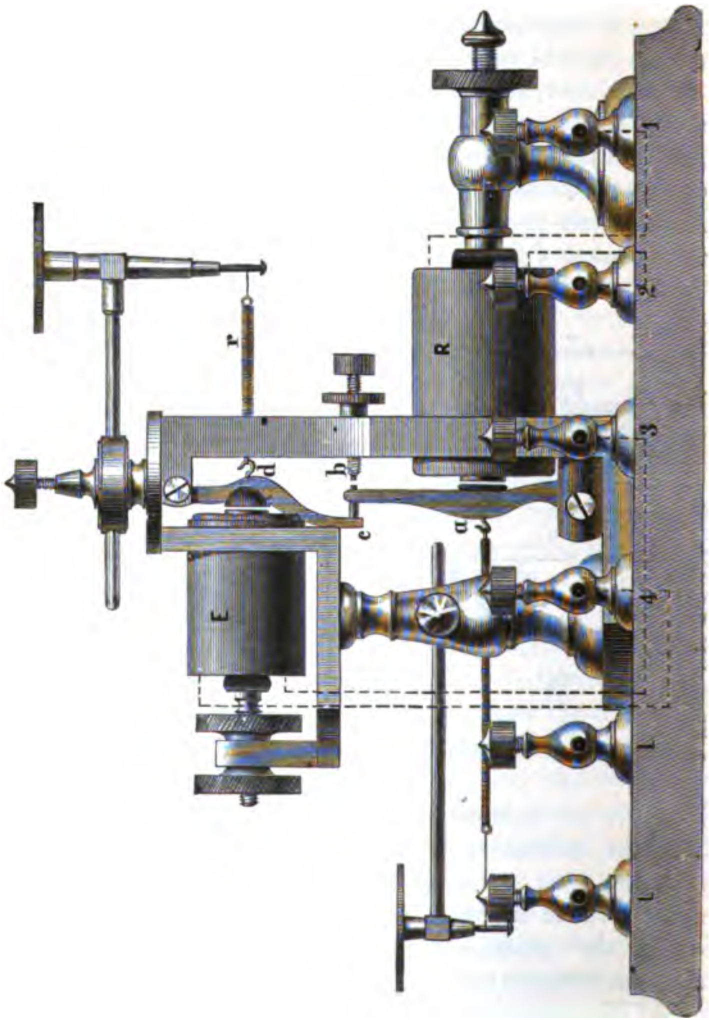


Fig. 248.

is so adjusted as to effect the release of the armature d' from the attraction of the magnet L$'$ before the armature a' is released from that of the relay magnet R$'$, the spring r' being also of sufficient strength to hold the armatures against the stop b' in opposition to spring h'.

If now the western circuit be again closed, the return of the armature lever a by the attraction of the relay magnet R closes the local circuit on that side of the repeater, followed by the closing of the eastern main circuit at l, and also of the extra local circuit E$'$ at p. The relay armature lever a' being again attracted by the relay magnet R$'$, upon the closing of the eastern circuit, no longer requires to be mechanically held against the stop b' by the armature lever d', and it is therefore drawn against the stop c' by attraction of the extra local magnet L$'$ consequent upon the closing of its circuit E$'$; but in thus returning the repeater to its normal position, it must be understood that in case the spring h' is of high relative tension, such tension being necessary in order that a break may be received at the relay R$'$ from the distant eastern station, a corresponding increased relative tension must be given to the spring r', otherwise the extra local magnet L$'$ will become sufficiently charged to overcome the spring r' and so draw away the armature lever d' before the relay magnet R$'$ becomes charged to the extent necessary in order to hold its armature a' in place, in which case it will be momentarily released and a false break ensue from a reverse action of the repeater. This forward movement of armature lever d' may, however, be retarded to any necessary degree, by a proper tension of the spring r', even though it be held almost constantly against the armature lever a', and yet a break from the distant eastern station be promptly effective, provided the relay R$'$ be properly adjusted to receive it. For instance, the distant receiving station breaks. We will suppose the western circuit to have been open at that instant, at the key of the sending operator. Instantly, upon closing it, the relay R closes its local circuit, followed by the closing of the extra local circuit E$'$ at p. The eastern main circuit, however, being open at the distant office,

the armature lever a' will be drawn back instantly upon the first forward movement of armature d'. Thus the action of the repeater may be reversed; it being understood, of course, that its opposite parts may be operated in precisely the same manner.

It should be remembered, that in closing the main circuits at l and l' by movement of armature levers H and H′, springs are used for the purpose on account of the additional contacts necessary to be made by the same levers, at their opposite extremities. Inasmuch as by this arrangement the main circuit is closed before that of the extra local, and remains closed an instant longer, it may be regarded as favorable to the action of the repeater. although not essential, its successful operation being entirely due to the principle applied, which is, that the ratio of the resistance of the extra local armature spring to the attractive force of its magnet is greater than the ratio of the resistance of the relay armature spring to the attractive force of the relay magnet, the combination being as shown in the diagram.

It is not, therefore, necessary to allow full play to the sounder levers, for the purpose of gaining time between the closing of the main and extra local circuits. On the contrary, they should have the least possible movement, with due regard to securing perfect connections at the spring contact points, and to convenience in reading.

Figs. 248 and 249 will illustrate the connections from the helices, contact points and switches, to binding screws arranged upon the base boards. The relay and its sounder of one side of the repeater are designated in the description by the letter A, and those of the other side by the letter B, by which plan the connections of the full repeater may be represented in drawings of one side only.

L and L, in fig. 248, are binding screws connecting respectively with the stop b and armature lever a, forming the contact points of the ordinary local circuit.

L and L, fig. 249, are also local circuit binding screws, connecting with the sounder coils L M, these four binding screws being connected together on the A side of the apparatus with a

local battery, in the same manner as those of an ordinary relay and sounder.

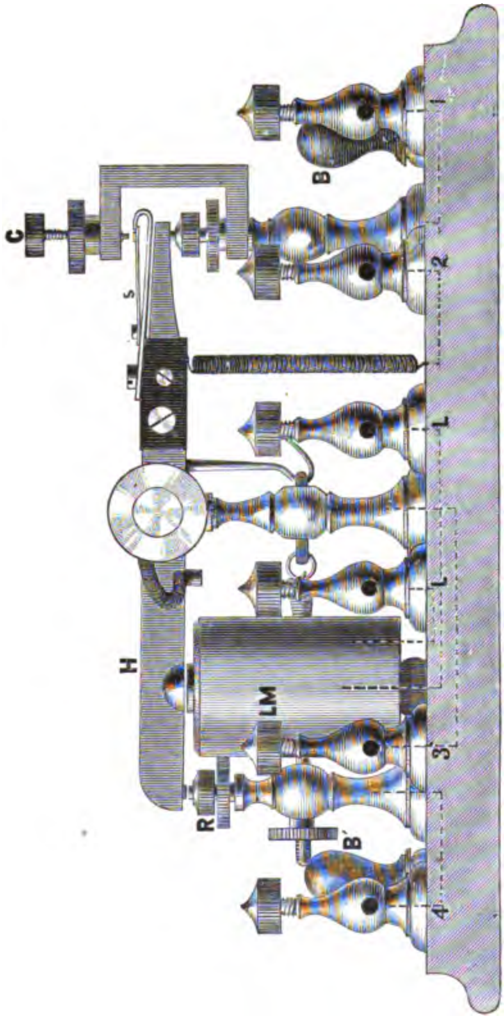


Fig. 249.

Duplicate connections are made at and between the other relay and sounder, consequently the relay of fig. 248 A operates the sounder of fig. 249 A, and the relay of fig. 249 B that of fig. 248 B.

Binding screws 1 and 2, fig. 248 A, are the terminals of relay coils R, and connect by wires, one with the key, thence to line, and the other with the binding screw 1, fig. 249 B; thence through the post and contact points formed by the adjustable screw C and spring *s* (the latter being insulated from the sounder lever H); thence by the spiral connecting wire, to the binding screw 2, at which point the circuit is completed by connection with battery and earth.

Binding screws 3 and 4, fig. 248 A, are the terminals of the auxiliary local coils E, and connect, one with a battery of one Grove cell or its equivalent, and the other by a connecting wire, with binding screw 4, fig. 249 B; thence through the post and contact points formed by the adjustable screw R, and sounder lever H; thence by the middle post to binding screw 3, which, being connected to the other pole of the Grove cell, completes the auxiliary local circuit.

The main and auxiliary local circuit connections between the binding screws of fig. 248 B and those of fig. 249 A are made in a similar manner to those described, referring to the same numbers; the internal connections being, of course, the same.

The switches B and B′, fig. 249, are used only for the purpose of connecting across the contact points of the main and auxiliary local circuits, when desirable to use each side of the repeater as an ordinary relay and sounder. One point of switch B, therefore, connects with binding screw 1, and the other with binding screw 2.

One point of switch B′ connects with binding screw 3, and the other with 4, this arrangement being the same on each side.

We have described Milliken's repeater at considerable length, for the reason that as it is much more generally used at the present day than any other, it is desirable that its principle and mode of operations should be understood by those engaged in the telegraphic service.

Experience shows that the armatures of the auxiliary local magnets need adjustment but seldom if the local batteries are in good working condition. The relays of the repeater are managed

in exactly the same manner as an ordinary relay. The sounder levers should have about the usual amount of play, but the tension of the retracting springs of the sounders should be very moderate, only a little more than enough to raise the armature when released by the magnet. When working most efficiently the apparatus usually has what may be termed a dragging sound. If the relays are properly adjusted the opposite side will always be able to break without difficulty, especially if the circuit is opened for about two seconds, as it should be, by the receiving operator.

More recently a repeater has been invented by Mr. Gerritt Smith, which may be considered an improvement upon the principle of Farmer & Woodman's apparatus, described on page 462. It is, however, not only more simple in its construction but more positive in its action, and has proved to be free from the objections which, as we have stated, led to the abandonment of that apparatus. In Mr. Smith's arrangement, the opening of the eastern relay, for example, opens the local circuit of its own sounder. The lever of this sounder when released, by means of a projecting arm, mechanically locks the armature of the western relay before breaking the western main circuit, which is done by a spring contact, as in the other repeaters which have been described. In practice this plan has given very excellent results.

CHAPTER XXXI.

THE EUROPEAN MORSE TELEGRAPH.

In the spring of 1838 Morse visited Europe, taking with him a set of his telegraphic apparatus, for the purpose of obtaining patents in England and France, and of endeavoring to make arrangements for the practical introduction of his invention abroad. In the latter respect, however, he was unsuccessful. The following year he returned, and devoted himself to the prosecution of his enterprise in the United States, until his efforts were rewarded by the completion and successful practical operation of the first line between Baltimore and Washington, in 1844, as detailed in the preceding chapter.

In 1845 Mr. C. J. Fleischmann exhibited the Morse apparatus to the Emperor of Austria at Vienna, the result of which was that it was officially adopted by the Austrian Government. In 1848 two Americans, Messrs. C. Robinson and C. L. Chapin, built a line from Hamburg to Cuxhaven, at the mouth of the Elbe, a distance of ninety miles, which was operated upon the American plan, with Morse's apparatus, and used for reporting marine news. Some years prior to this date Steinheil's apparatus had been adopted by the Bavarian Government, but little or nothing had been done towards putting it in actual operation beyond the construction of a short line between Munich and Augsburg. W. Fardley, of England, had also succeeded in introducing Wheatstone's dial ap·aratus to a limited extent on several of the railways of North Germany. This instrument was only capable of being worked at a very slow rate of speed, and for comparatively short distances, in both of which respects it was far inferior to the Morse apparatus. The superior efficiency of the latter in working direct through long distances depended mainly upon the application of the relay and local

circuit. This improvement was used on the Hamburg line, although its existence was at that time carefully kept secret, doubtless for the reason that, if made known, it might have been employed to increase the efficiency of rival systems. In 1849 Robinson and Chapin undertook the equipment of a line between Berlin and Vienna. During that year Steinheil was commissioned by the Bavarian Government to travel through Germany and examine the different systems of telegraphy then in operation, in order to determine which was best adapted for use in that country. In the course of his investigation he visited the line between Hamburg and Cuxhaven, above referred to. After his return home he received an appointment from the Austrian Government in the Ministry of Commerce, for the purpose of permanently organizing the telegraphic system of that empire. In October, 1851, a convention of deputies from the German States of Austria, Prussia, Bavaria, Wurtemberg and Saxony met at Vienna, for the purpose of establishing a common and uniform telegraphic system, under the name of the German-Austrian Telegraph Union. The various systems of telegraphy then in use were subjected to the most thorough examination and discussion. The convention decided with great unanimity that the Morse system was practically far superior to all others, and it was accordingly adopted. Prof. Steinheil, although himself, as we have seen, the inventor of a telegraphic system, with a magnanimity that does him high honor, strongly urged upon the convention the adoption of the American system, on the ground of its intrinsic superiority, not only to his own but to all others. The inconvenience of the spaced letters in Morse's original alphabet, which has already been referred to in connection with the description of the American system, had been avoided in Germany from the outset. A modified alphabet had been arranged by Dr. Clemens Gerke, a telegraphic engineer of Hamburg, which was used on the earliest lines of North Germany, and another and different one had been employed on the Bavarian and Austrian lines by Steinheil. The Vienna Convention, among other measures, adopted a new and uniform international alpha-

betical code, which has since become universal in all parts of the world where the Morse apparatus is used, except in America. The arrangement of this alphabet is as follows:

LETTERS.

A	·—	L	·—··	W	·——
B	—···	M	——	X	—··—
C	—·—·	N	—·	Y	—·——
D	—··	O	———	Z	——··
E	·	P	·——·		
F	··—·	Q	——·—	Ch	————
G	——·	R	·—·	Ä	·—·—
H	····	S	···	Ö	———·
I	··	T	—	Ü	··——
J	·———	U	··—	É	··—··
K	—·—	V	···—	Ñ	——·——

NUMERALS.

1	·————	4	····—	8	———··
2	··———	5	·····	9	————·
3	···——	6	—····	0	—————
		7	——···		

PUNCTUATION, ETC.

Period (.)	······
Comma (,)	·—·—·—
Query (?)	··——··
Exclamation (!)	——··——
Apostrophe (')	·————·
Hyphen (-)	—····—
Fresh paragraph,	·—·—··
Inverted commas,	·—··—·

Parenthesis,	— - — — - —
Understand,	- - - — -
I don't understand,	- - — — - - - - — — - -
Wait,	- — - - -
Erase,	- - - - - - - - -
Call signal,	— - — - — - —
End of message,	- — - — - — -
Cleared out all right,	- — - - — - - — -

The accented é is important in French to distinguish between the past participle and the present tense. The apostrophe is equally necessary in French, thus: C'est, l' intention, de l' Empereur, etc.

The ä ö ü are important in German.

The Spanish ñ is seldom used.

The period (.) is generally written in three pairs, the mind counting 3 more easily than 6, thus:

- - - - - -

The erasure is frequently divided into 3 threes, and for the same reason, thus:

- - - - - - - - -

It is used as follows:

Suppose the operator to have mispelled a word, he gives the nine dots (the erasure signal), goes back to the word before the error, repeats it, and continues.

In compiling the above alphabetical code, the characters for C, F, L and R were taken from Gerke's alphabet; O and P from Steinheil's; the letter X and the numerals 1, 2, 3, 4 and 5 from that introduced by M. Lefferts on the American Bain lines in 1849; while the numerals 6, 7, 8 and 9, also taken from this alphabet, were arranged in reverse order for the reason given below. The remaining alphabetical characters of the American alphabet were preserved. It will be noticed that in the international code each numeral is composed of five elements, systematically arranged, the first half checking the second half of the character, and so

rendering them as free from ambiguity as they are easy of recollection by the mind. There are thirty-two characters in the international alphabet, those in addition to the ordinary twenty-six being necessary to cover peculiarities in the French, German and Spanish languages.

THE REGISTER.

The Morse apparatus first used on the Continent, in 1849-50, was copied very closely after the American instruments of that period, specimens of which had been brought from the United States by Messrs. Robinson and Chapin. Fig. 250 represents one of the registers first used, which is so nearly identical with some of the American instruments illustrated in the preceding chapter as to require no detailed description. Instead of the weight formerly used in the American pattern a coiled spring is made use of to drive the wheel work. In the register illustrated in fig. 251 the weight is used, but is suspended upon an endless chain, so that it can be wound up without stopping the machinery. Fig. 252 represents a register of Siemens and Halske's design, in which the wheel work is protected from dust by being enclosed in a combined brass and glass case. The rollers which carry the paper strip are placed upon the side of the instrument instead of at the top, and this renders it much easier to start the paper than in the former arrangement. Fig. 253 represents an instrument designed and constructed by Siemens and Halske, which was formerly extensively used in the telegraph lines of Russia, Denmark and Hanover. The movement of the writing lever is effected by the attraction of the opposite poles of two electro-magnets, rendered active by the same currents. *m m′* are two straight electro-magnets; the core of *m′* is furnished with a soft iron pole-piece or continuation *r* on each of its poles; the core of *m* is supported between two screw-points and is also furnished at each end with a pole-piece *p*, ending in a facing opposite to and of the same size as *r*. Between the two pole-pieces *p p* is a frame carrying the writing lever. The ends of the coils of the electro-magnets *a b* and *a′ b′* are electrically

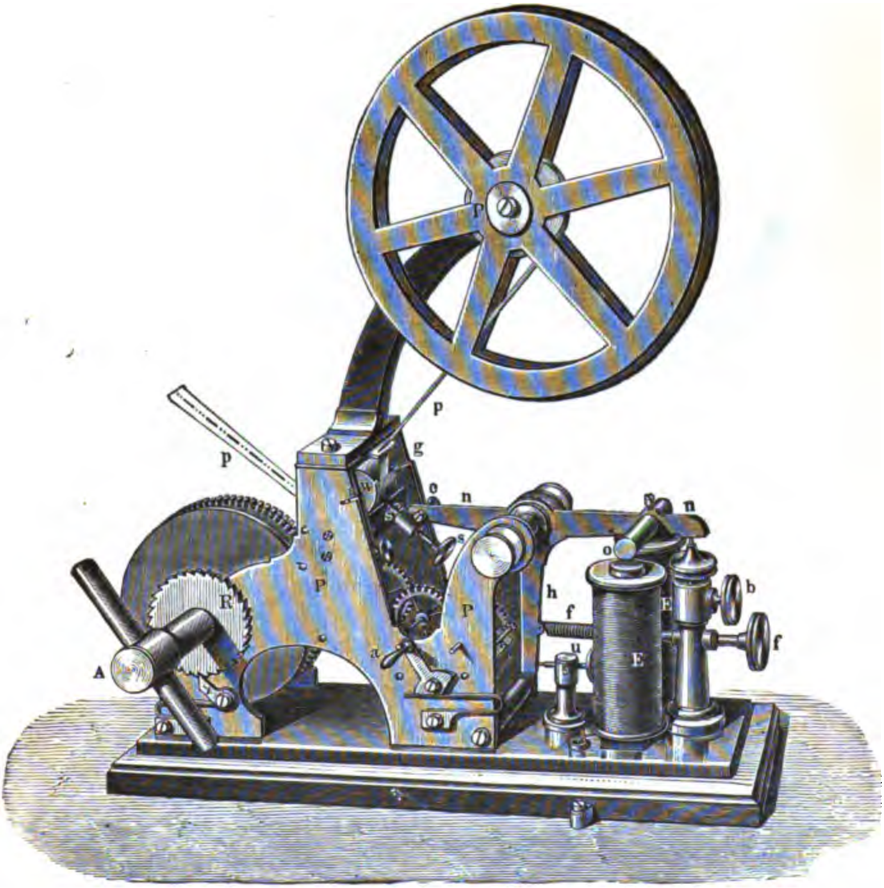


Fig. 250.

connected with the terminals A and B. The attraction of these four poles in the same sense renders the instrument extremely delicate, and the force with which the poles tend to approach each other being very great, ample power is given for recording the signals perfectly.

In the earlier experiments of Morse, as far back as 1836, methods of marking the paper by the direct action of the armature lever were tried by him. Not only a common lead

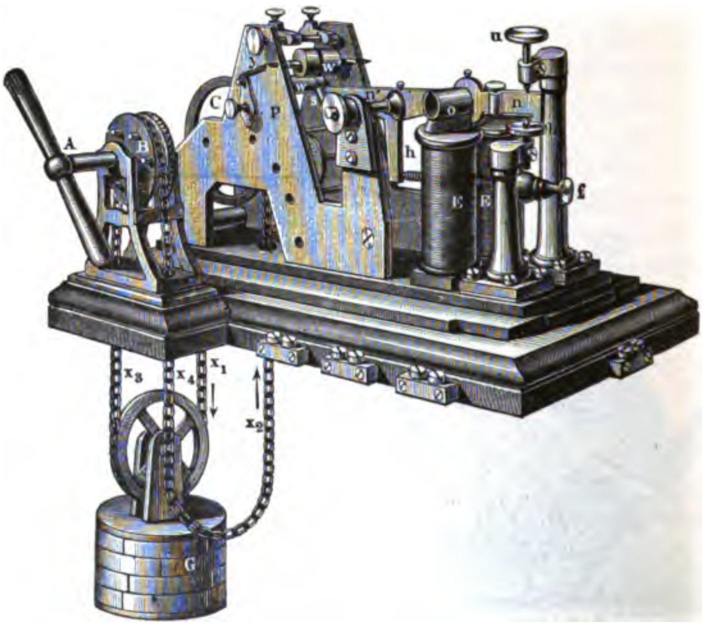


Fig. 251.

pencil, but fountain pens of various kinds, and a small printing wheel or roller was employed at different times. The latter, together with a sponge which was placed in contact with it for the purpose of supplying it with ink, were mounted upon the armature lever above the paper strip. All these devices were used with more or less success, but were finally abandoned in favor of the style or steel point, by which the characters are embossed upon the paper.

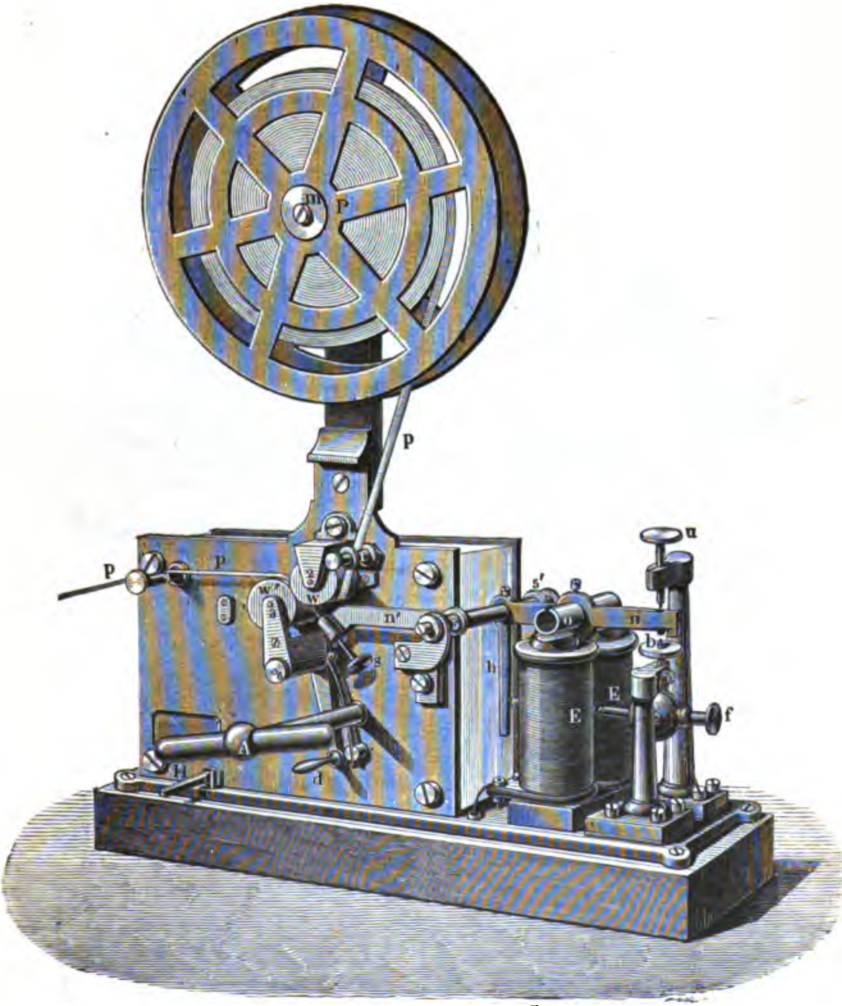


Fig. 252.

The embossing register had been in use but a few years on the lines of the German-Austrian Union before numerous experiments were made, with a view of substituting for it some effective and convenient method of recording by means of ink, or some similar coloring matter. The earliest apparatus of this kind which appears to have been practically successful was that of Thomas John, of Prague, an assistant engineer in the Austrian

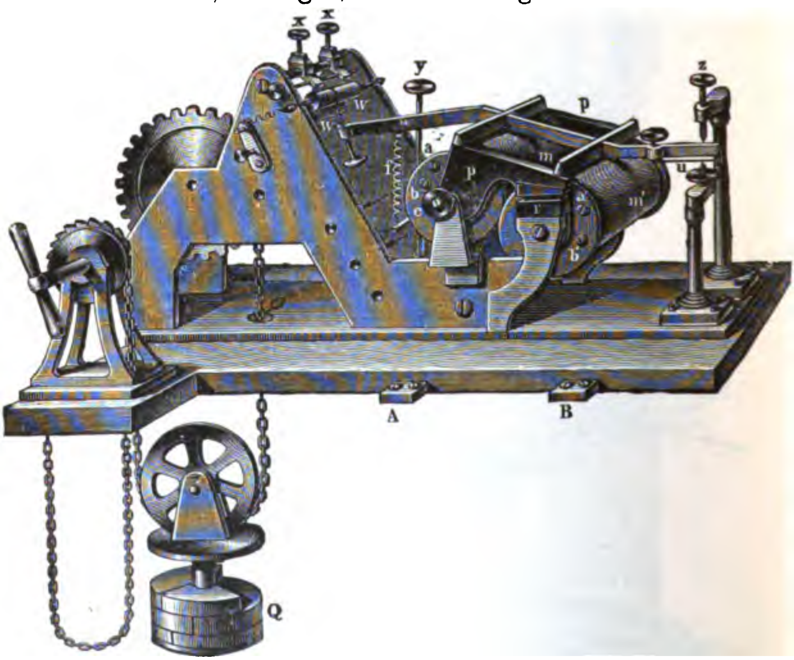


Fig. 253.

telegraph service, which was first used in the Central Telegraph Station in Vienna in 1854. It differed from the original plan of Morse in several respects. The marks were made upon the paper by means of a small printing wheel kept constantly revolving in a dish of colored fluid, and pressed gently against the paper when the armature of the electro-magnet was attracted. The object of John's arrangement was to lessen the force required for marking the paper, so that the instrument might be

worked directly in the main circuit without the use of relays and local batteries. In this respect the apparatus, at least with its numerous subsequent improvements, has been a complete success.

John's arrangement was afterwards taken to Paris, where it underwent important modifications by Digney, which not only simplified its construction but greatly improved its working.

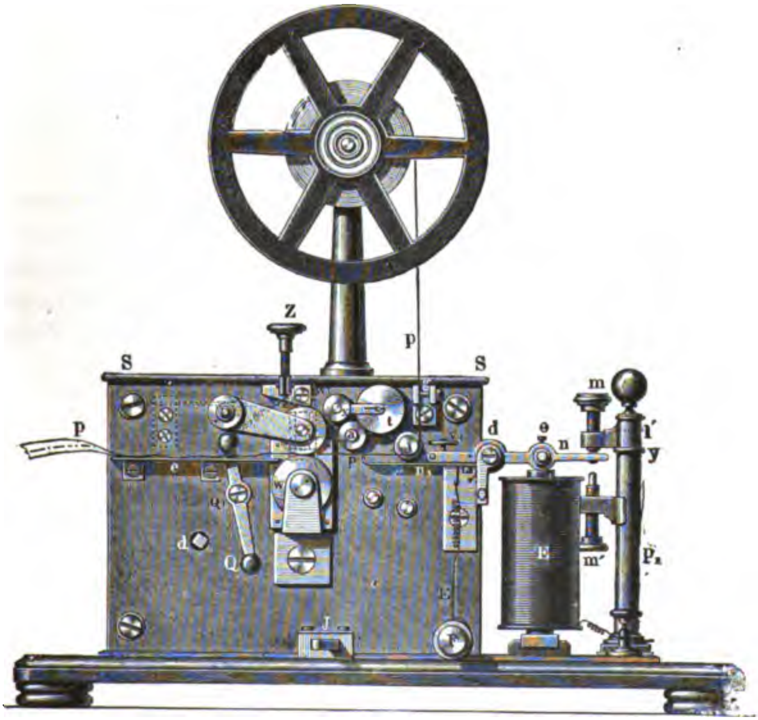


Fig. 254.

The Digney ink writer is shown in fig. 254, in the form in which it is extensively used in Europe. The clock work is driven by a coiled main spring, and is enclosed within a brass case S S, which protects it from dust and injury.

On the sides of the case, in front, are the paper rollers W and W_1, the former being carried by the mechanism and the latter

by friction. The paper strip p passes between these rollers, and the pressure of the upper upon the lower roller is regulated by a spring which is adjustable by means of the screw Z.

When a strip of paper p is to be inserted, the end is taken from the roll on the paper reel P, passed through the slit g, and under the guide-pulley i, thence under the printing wheel a, and between the paper rollers W and W_1, the latter being lifted for the purpose by means of a lever q when shoved to the left. After passing between the rollers the paper moves along the slide e. The electro-magnet is seen at E; o is its armature, and $n\ n_1$ the writing lever. The latter is firmly attached to the armature and turns upon an axis at d. It is provided with a retracting spring E, adjustable by means of the screw F.

When the armature is attracted to the poles of the electro-magnet, a knife-edge, which forms the end of the spring n_1 is raised, and lifts the paper against the printing wheel a, which revolves in the opposite direction to the movement of the paper, against which it rubs so long as the armature is attracted. When the current ceases, the spring E pulls back the lever, and the paper strip is removed from contact with the wheel a. The ink roller t is of felt or flannel, is occasionally moistened with fresh oil color, black or blue, by means of a brush. The printing wheel a, which has quite a sharp edge, revolves in contact with the ink roller, and is by this means kept constantly supplied with ink. The screw stops m and m_1 regulate the play of the armature lever. The brake j serves to start and stop the clock work when a communication is to be received.

The roller t does not require to be inked oftener than once a day, even when the instrument is constantly at work. The clock work is arranged to run about an hour, and to carry the paper along at the rate of four feet per minute. The paper strip is quite narrow, and is only used once.

This instrument, working as it does without the aid of relays or local batteries on lines of ordinary length, has become a great favorite with the telegraphic employés in all parts of Europe. The deciphering of the characters when written in ink is much

less fatiguing than when they are embossed, especially if the light is at all imperfect. The Digney instrument has given such satisfaction to the French Administration that it has been adopted by them for use on all the government lines both in France and in the Colonies. The satisfactory operation of the Digney instrument is, no doubt, due in a great measure to the nice discrimination between the sizes of the movable and fixed portions of the apparatus, which has greatly reduced the inertia of the armature lever, etc., while retaining abundant strength to effect the marking with distinctness.

A series of interesting experiments was made by M. Guillemin, in 1862, in order to determine the maximum number of elementary signals, and from this the number of words it was capable of recording in a given time. He employed a transmitting apparatus, consisting of four wheels mounted upon a common axis; the first of which transmitted dots, the second dashes, whilst the two others served to discharge the static electricity from the line after each signal.

The words *France* and *Paris*, which, in the Morse alphabet, represent an average of the length of the words in the language, were repeated in a line of 470 miles in fine weather thirty times per minute, and in wet weather he easily attained the rate of forty words per minute. On a line of 280 miles the speed of recording was augmented to seventy-five words per minute.

Another style of French ink-writer is arranged with an endless chain in place of the printing roller *a*, running over two pulleys moved by the clock work of the apparatus. It receives the ink from a roller placed above it, as in Digney's instrument, and, in like manner, the paper is pressed against it by the armature lever.

The ink-writer of Siemens and Halske, which is represented in fig. 255, is very largely used in Germany, and also on the government telegraph lines in Great Britain and India. It is regarded as an improvement upon the apparatus of Digney, in which the writing is sometimes rendered indistinct by the thickening of the ink upon the roller in warm weather; it is liable,

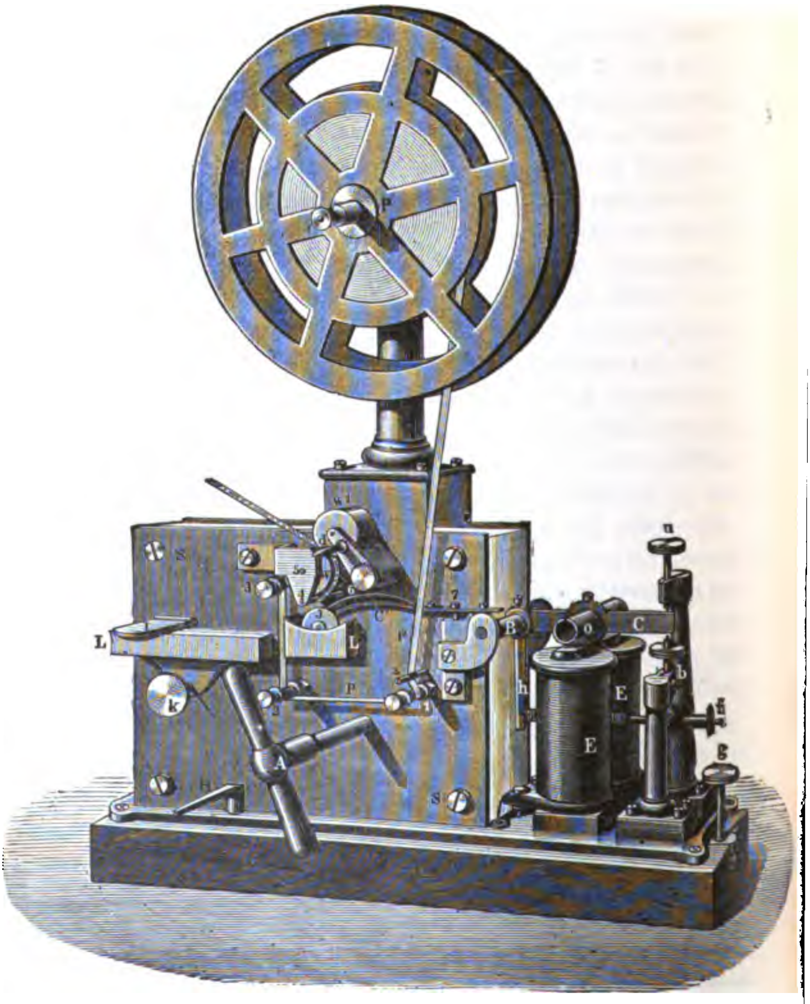


Fig. 255

also, to be blotted when the ink upon the roller is being renewed, unless considerable care is exercised. In the Siemens-Halske instrument these difficulties seem to be completely overcome. The principal difference between this apparatus and that of Digney consists in the arrangement of the printing apparatus: The parts are, in fact, reversed. The printing wheel revolves with its lever half immersed in a dish of coloring liquid, while it is lifted by the action of the armature up against the paper which runs above it, instead of the paper being moved against the printing wheel. This was, in fact, John's original mechanical arrangement, but was, of course, but incompletely worked out by him at that early day.

The clock-work is enclosed in a case with brass sides, having plates of glass inserted at the top and ends, and is driven by a coiled main spring, which is wound up by the key A. The paper strip passes from the reel P around the guide pulleys 1, 2, 3 and 4, and thence between the paper rollers w and w_1 and so out. The roller w is carried by the clock-work at a uniform speed, while w_1 presses against it and is carried by friction. The latter may be lifted by the handle d in order to insert the paper conveniently. The inking wheel J is also caused to revolve by the clock-work, its axis being arranged as shown in fig. 256, a swivel joint U connecting it with the frame S S, so that it may be lifted by the armature without interfering in the least with the continuous revolution which is imparted to it through the pinion. The armature o of the electro-magnet E_1 E is attached to the lever C, which turns upon an axis at B. The arm C_1, attached to the lever C, takes hold of the arbor of the printing wheel J, as shown in fig. 256, and raises the latter whenever the electro-magnet attracts its armature. The inking wheel J, whenever it is lifted, revolves with its lower half in the ink reservoir L L, which is filled through an opening beneath the cover l. A spring 6, fixed upon the writing lever C_1, is arranged with its free end almost in contact with the periphery of the wheel J, for the purpose of removing therefrom any superfluous ink.

The retracting spring of the lever C is attached to an arm *h*, and adjusted by a screw *f*, as in the American instruments. The clock-work is stopped and started by means of a friction brake, H. As this apparatus is intended to work on the main circuit, the electro-magnet E E_1 is also made movable, like that of a relay, the adjustment being effected by a lever beneath the base controlled by the screw *g*.

When a coiled spring is employed instead of a weight as the moving power of a Morse register, it is desirable that some means should be provided which will enable a new spring to be substituted for a damaged or broken one without much loss

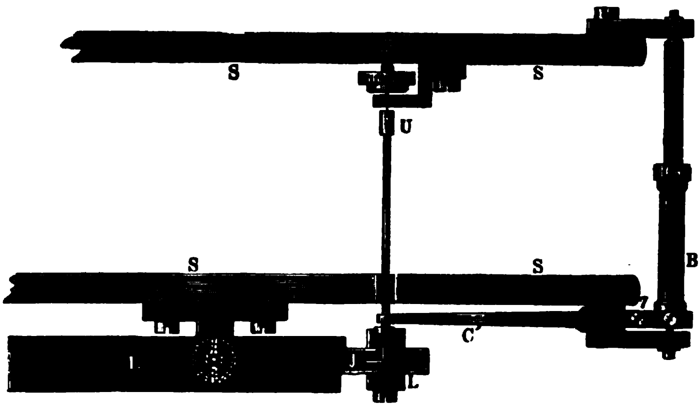


Fig. 256.

of time. This is accomplished by means of an attachment invented by Gurlt, a mechanician of Berlin. The main driving wheel of the clock-work is fixed to a hollow axis B, fig. 258, within which is placed the steel arbor A, fig. 257. The enlarged portion C of the hollow axis projects outside the case of the apparatus, and is formed with a projection E, which fits into a corresponding recess in the hub *i* of the spring box in fig. 257. The latter is then secured in position by screwing the handle K upon the thread formed upon the end of the arbor A at *r*. Thus, if the main-spring of an instrument breaks, it is only necessary to unscrew the handle K and take off the spring

box, replace it with a spare one, and screw the handle on again, which can be done in a few moments. This arrangement is very generally used upon the best European instruments.

The recording instrument is sometimes provided with a self-starting and stopping device, by which means a despatch may be written out at a distant station in the absence of the operator. The earliest device of this kind was that used by Morse on the experimental line between Baltimore and Washington, and which has been referred to on page 428. The arrangement

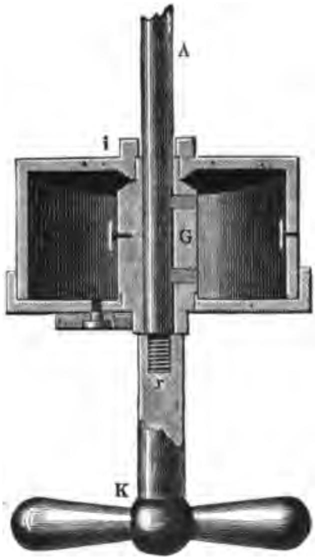


Fig. 257.

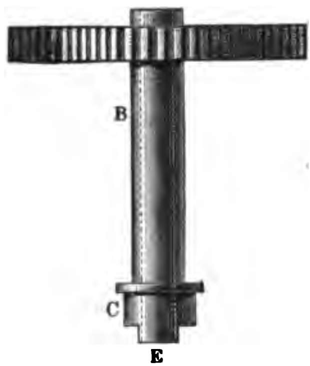


Fig. 258.

employed by Siemens and Halske is shown in fig. 259. A separate electro-magnet A B, called the releasing magnet, is placed near the electro-magnet which operates the writing lever of the register, and in the same circuit. The armature C of the releasing magnet is carried by a lever which turns upon an arbor at H. At the other end of the lever is a friction spring O E, which, when the electro-magnet A B is inactive, presses upon the brake wheel F by means of a weight. The brake

wheel being on the last axis of the wheel-work of the register, the latter is stopped by the friction whenever the circuit of the electro-magnet A B, and of the register magnet is open. When, however, the armature is attracted, the friction spring E is raised from F, and the wheel-work of the register starts; a boot I hanging from the lever and resting upon the periphery of the revolving drum M, is lifted up, and continues to dance upon the rim by the friction of the moving drum. When the current ceases the armature is released, and the boot, descending upon the drum M, is carried along by the rotation of the latter in the direction of the arrow, but does not permit the spring E to drop down and stop the wheel-work until some seconds after the

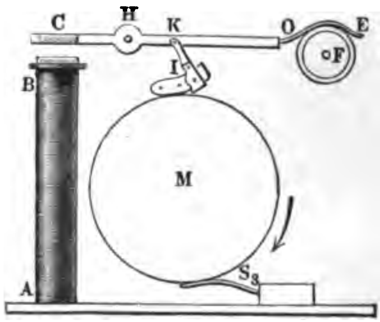


Fig. 259.

cessation of the last current. The drum M is placed upon one of the slower moving axes of the train.

Another device of this kind, which has proved very satisfactory in practice, is shown in fig. 260. The electro-magnet M M, armature *m*, writing lever *b*, and wheel-work are arranged in the usual manner. On the second axis *r*, which carries the pinion which gears into the large spring-wheel R, is a small cylindrical box *z*, which encloses a movable steel disk with a projecting catch *n*. The centre of the steel disk is bored out in order to accommodate a spiral spring (see fig. 262), which tends to press the catch *n* in the direction of the arrow, against the sides of the recess through which it projects. The lever *x p*

(fig. 260) turns upon the axis *o o*, its upper end *x* being constantly drawn to the right by the action of the spring *q*. The lower end of the lever is jointed at *p* to a rod *p q*, which termi-

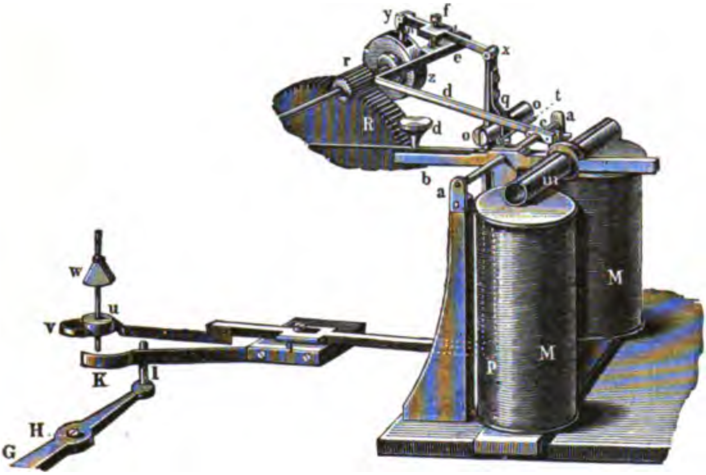


Fig. 260.

nates in an elastic brake *v*, capable of stopping the wheel-work by friction against the brake wheel *u* on the last axis of the train, whenever brought into contact with it. The lever G H I and friction brake K is the ordinary arrangement for stopping

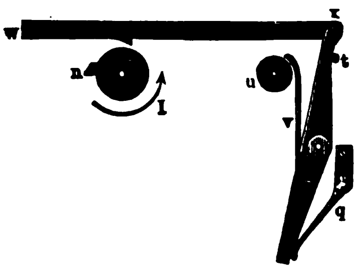


Fig. 261.

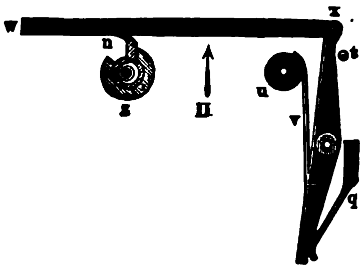


Fig. 262.

and starting the machinery by hand. A bent arm *c d e* is fixed upon the arbor *a a* of the writing lever *b*, which terminates at *e* in a flat surface, in which two pins are inserted. Between these

pins and above *e* passes the detent lever *x y*, ending in a hook *y*, which takes hold of the catch *n*, previously referred to, when the adjusting screw *f* is properly regulated. The principle of the action will be readily understood by reference to the diagram, fig. 262, which represents the apparatus at rest. The first movement of the armature throws up the detent lever *x y* and releases it from the catch *n*, whereupon by the action of the spring *q* the brake *v* is instantly removed from the drum *u*, and the clock-work starts. When the message is completed and the detent *y* comes to rest, the catch *u* is gradually carried round in the direction of the arrow in fig. 261, until it comes into the position shown in fig. 262, and again stops the machinery.

THE KEY.

The telegraph lines in Europe are usually worked on what is termed the open circuit arrangement, the details of which will be more fully described hereafter. Two different systems of working are employed in connection with the open circuit, viz., the single current and the double current system. The former is used principally in Germany and elsewhere on the Continent, while the latter is much used in Great Britain and India, especially for long circuits. The single current key simply opens and closes the circuit of the battery, sending to the line each time it is closed a current of the same polarity and interrupting it when opened. By reference to fig. 263 it will be seen that the single current key for open circuits, sometimes called a three point key, differs in its connections from the American or closed circuit key described on pages 442–443, being provided with two sets of contact points *a a′* and *c c′*, the former being closed when the key is depressed and the latter when it is raised. The key is normally retained in this position by the action of the spring *f′*, and is then said to be open. The points *a a′* are termed the front or working contact, and *c c′* the back or resting contact. The axis of the key *b* is usually connected with the line L, as shown in fig. 264, the rear contact with the instrument, and thence to the earth, while the front

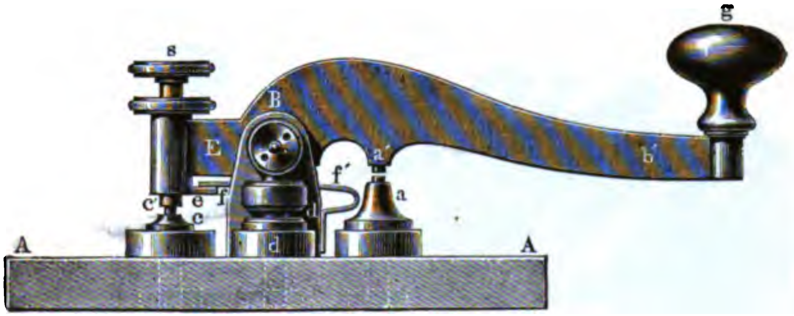


Fig. 263.

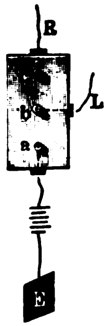


Fig. 264.

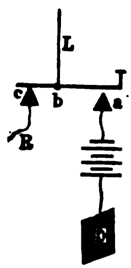


Fig. 265.

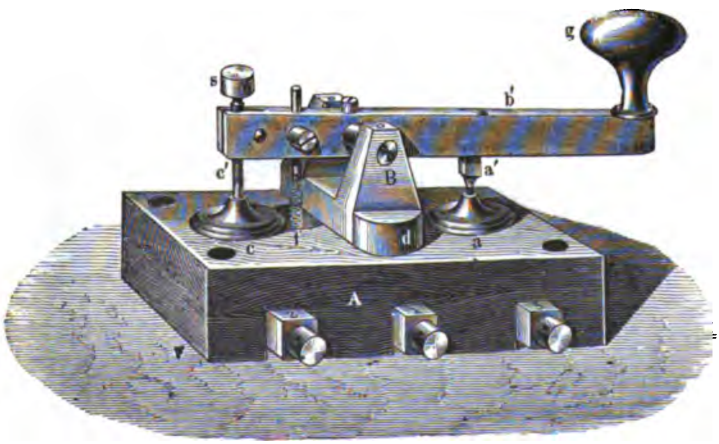


Fig. 266.

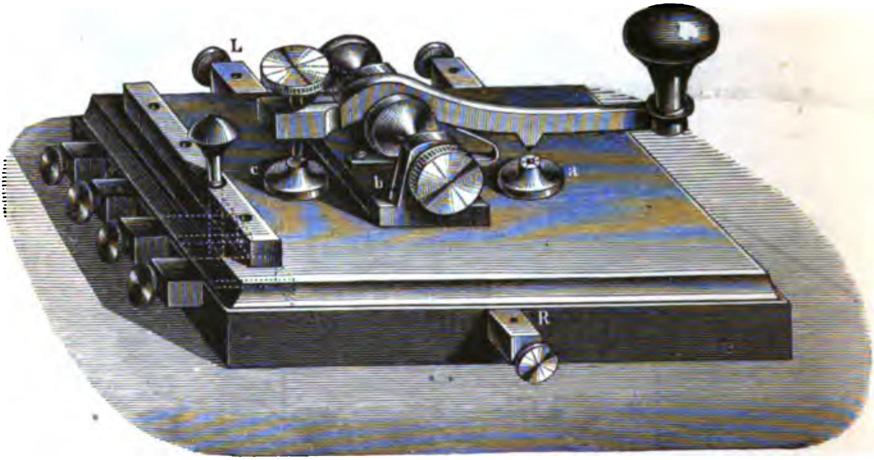


Fig. 267.

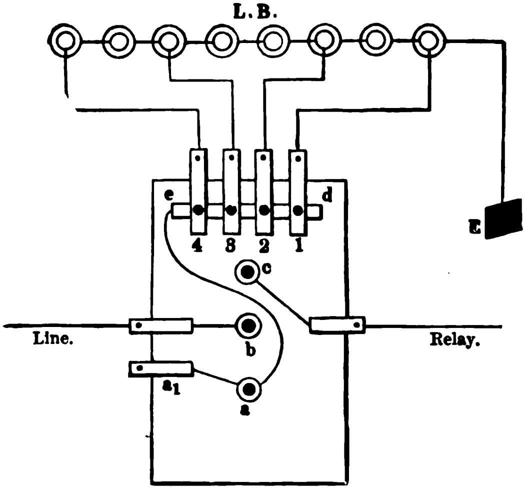


Fig. 268.

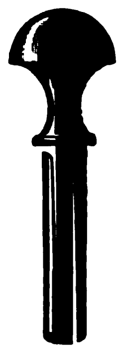


Fig. :69.

contact is connected with one pole of the battery. When describing or referring to the key in connection with other parts of the apparatus, it is customary as a matter of convenience to represent it in the manner shown in fig. 264 or 265. The front or working contact is always indicated by the letter *a*, the axis of the lever by *b*, and the back or resting contact by *c*. The exact form of the key is of course various, different manufacturers having different patterns. Fig. 266 shows the construction now generally adopted by the European manufacturers, in which the lever is straight instead of curved, as in fig. 263.

Fig. 267 represents a form of key which is much used on the Austrian lines, which is provided with a battery switch or commutator. The arrangement of the connections will be readily understood by reference to the diagram or plan view, fig. 268. By inserting the spring peg shown in fig. 269 in the appropriate hole in the commutator, any required proportion of the main battery L B may be placed in connection with the working contact *a* of the key.

The double current key, which is used for long circuits in England, India and other countries, is so arranged as to completely reverse the battery after each signal; that is to say, instead of the spaces between the signals being formed by merely breaking the circuit, a reverse current is sent into the line, so that the battery when working is always connected to the line in one direction or the other. Fig. 270 shows the arrangement of the double current key usually employed in England. The line wire is attached to binding post 3; the ground wire and one side of a polarized relay to 7, the other side of the relay being connected to 4. The positive pole of the battery is connected with the binding post C, and the negative pole with Z. L L′ are two levers, insulated from each other, and moving upon the same fulcrum by pressing upon the knob attached to L′. s s''' are two insulated springs connected with Z, and s' s'' are two similar springs connected with C. When the knob of the key is depressed a positive current is transmitted through the spring

Fig. 270.

s' along the lever L′ to button o, thence by switch S′ and screw post 3 to line; and a negative current is sent through spring s along the lever L to button q, thence by switch S″ and screw post 7 to earth and one side of the relay, the other side of the relay being connected with screw post 4 and button p, which is disconnected when the switch S is turned to send.

When the knob of the key is not depressed the levers L and L′ rest upon springs s'' and s'''. A negative current passes from spring s''' to lever L′, and thence to button o and switch S′ to screw post 3 to line, and a positive current passes from spring s'' to lever L, button q, switch S″, and screw post 7 to earth. Thus the line is always charged either with a positive or negative current, whether the key is raised or depressed. When the switch is turned to receive, the battery is disconnected; the current from the line enters at screw post 3, passes to switch S′, button p, screw post 4, and thence to the relay and ground. When the switch is turned to send, the line wire is disconnected from the receiving apparatus, and the receiving operator cannot stop the sender until the switch is turned from send to receive. Sometimes a tell-tale galvanometer is used, wound with two separate wires, one of them in the sending and the other in the receiving circuit. In sending the receiving coil is switched out of circuit, but the sending coil is affected by both out-going and in-coming signals, and the breaks of the receiving station are readily felt.

Fig. 271 shows a key intended for working a line on the Morse system by means of alternate positive and negative currents generated by an induction apparatus, dispensing altogether with the main batteries. It differs from the ordinary key merely in being provided with two front or working contacts a and b, one of which a is fixed upon a spring B, and when the key is depressed, is closed slightly in advance of the stationary contact b. The manner in which the key is connected will be explained in another place.

Siemens and Halske's magneto-induction key is used for the same purpose as the preceding one, except that the induced

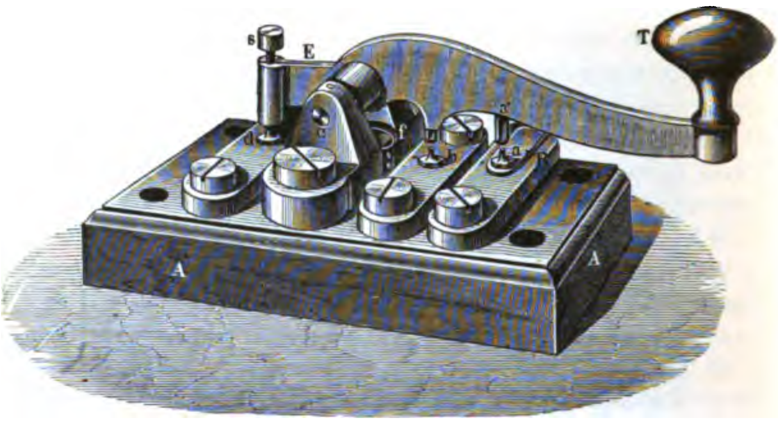


Fig. 271.

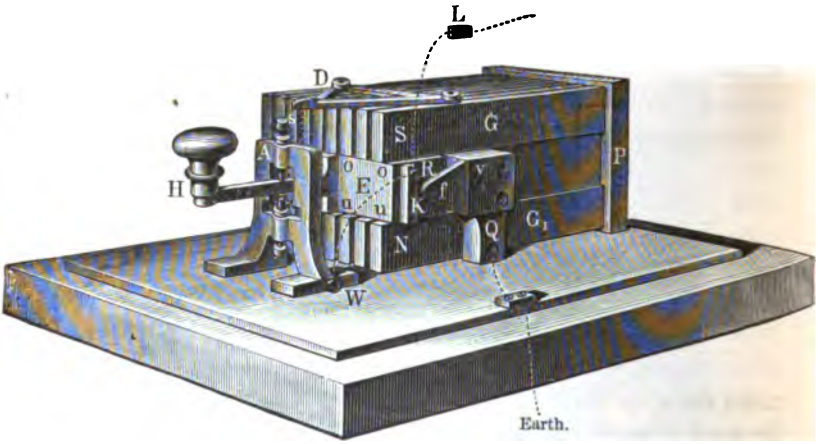


Fig. 272.

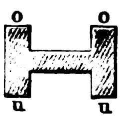


Fig. 273.

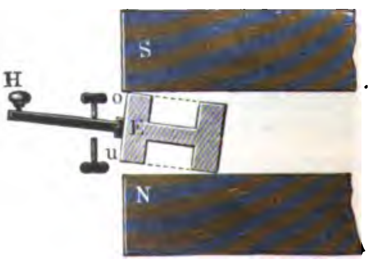


Fig. 274.

currents are produced through the agency of a powerful combination of permanent magnets. This form of key is shown in perspective in fig. 272. S and N are two rows of permanent bar magnets; the upper ones with their north ends and the lower ones with their south ends in contact with a heavy plate P of soft iron. The soft iron armature or inductor is as long as the magnet system is wide, and is cut in deep longitudinal grooves, as shown in the cross-section, fig. 273. This is mounted upon two screw points between the poles of the magnet system, and is capable of being oscillated in an angle of a few degrees by means of a handle H, fig. 274 and 275, so that when this is

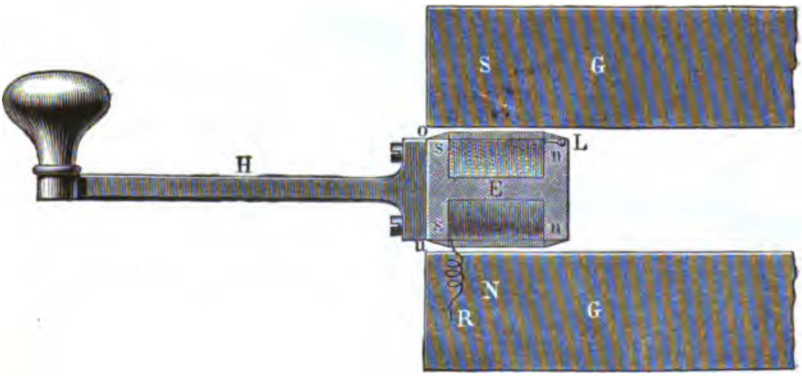


Fig. 275.

raised the upper edge of the armature *o o* comes in contact with the south pole S of the compound magnet system, and when depressed the lower edge *u u* in like manner comes in contact with the north pole N. The play of the lever or handle H is limited by adjustable screws fixed in the frame A. The normal position of the key is that shown in fig. 274, and it is maintained in that position by the spiral spring S, attached to the triangle D. A coil of fine insulated wire is wound longitudinally in the grooves of the armature or inductor E, as shown in fig. 276. One end of the coil wire of the inductor is attached to the screw *k* on the terminal K, from which one connection goes to line and another

to the screw *w* at the foot of the frame A. The other end of the coil is connected with the metal frame supporting the armature, and through the axis *f* to the upright support Q, from which a wire is carried to the terminal *t* and thence to the earth. When a current arrives while the instrument is in circuit with the line, it passes from L by the way of R W and the upper adjusting screw in A, through the handle H, axis *f*, Q, *t*, to the earth, without traversing the coil. This is the object of the connection between R and W. When the handle is depressed the polarity of the armature is reversed, and a positive magneto-electric current induced in the coil, which circulates also in the

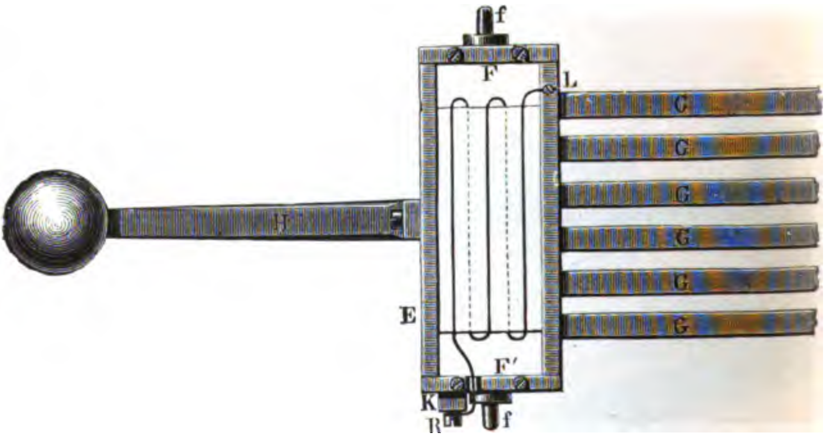


Fig. 276.

line wire and deflects the tongue of the polarized relay (hereafter to be described) at the receiving station, and closes the local circuit so long as the handle is held down, and no negative current is induced by permitting the key to return to its normal position.

By the use of the magneto-induction key the main batteries are entirely dispensed with, and the work is done by means of alternate positive and negative pulsations. A polarized receiving instrument is required, as in the case of the key used on the lines in Great Britain, described on page 499.

THE RELAY.

The relay first used in Germany, like the register, was very similar in its construction to the American instrument of corresponding date, from which it was copied. Fig. 277 shows this form. The upright electro-magnet M M is usually wound with about 7,000 or 8,000 convolutions of No. 36 wire. The different parts require no particular description, as they are essentially the same as in the instruments described in the

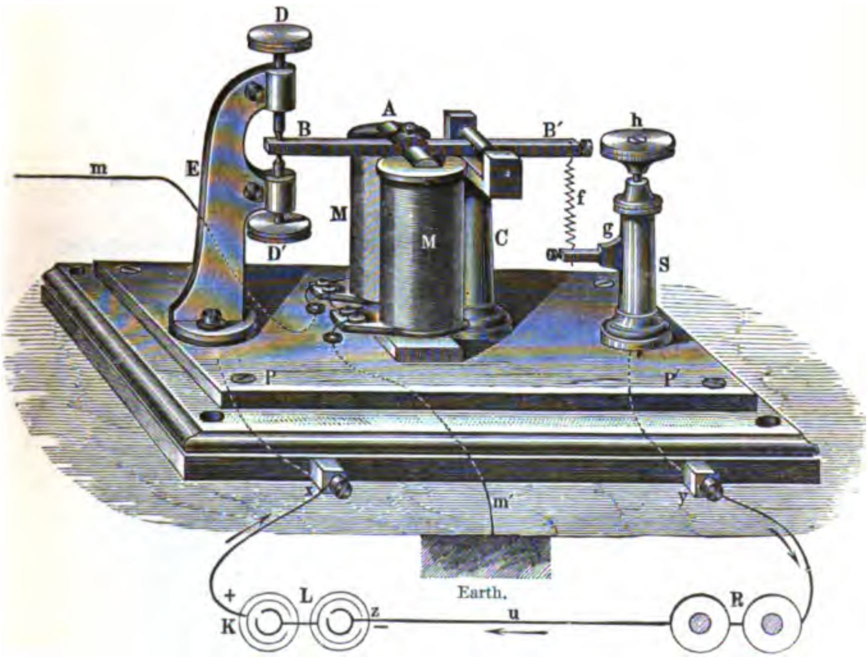


Fig. 277.

previous chapter. The arrangement for adjusting the retracting spring *f* is somewhat peculiar. It consists of a hollow pillar S, within which moves a steel screw having a milled head *h*. The projecting arm *g* on this pillar slides up and down in a slot. The vertical screw passes through it, and thus by turning the milled head *h* to the right or left the tension of the spring *f* may

be adjusted as required. The connections are shown in outline, m being the line and m' the earth wire, R the register magnet and L the local battery.

In introducing the relay into diagrams of apparatus it is often represented in the conventional manner shown in fig. 278, in

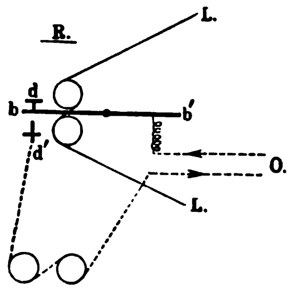


Fig. 278.

which b b' is the armature lever, d the insulated or resting contact, and d' the closing or working contact. L L represents the main circuit, and the dotted lines O the local circuit.

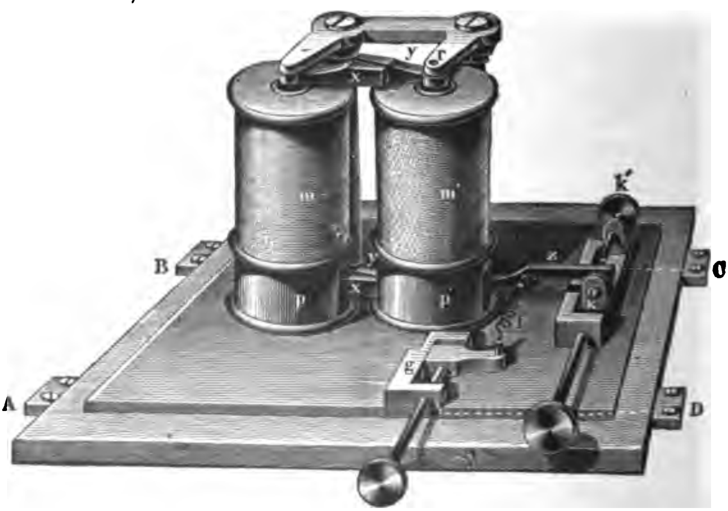


Fig. 279.

Various other forms of relays have been introduced in Europe from time to time, some of which we will proceed to describe.

A relay designed by Siemens and Halske, with a movable core, but without an armature, is shown in fig. 279. The principle is the same as that of the register described on page 486. This instrument has been much used in Russia, Denmark and Hanover. The helices m m' are electrically connected in the usual manner, A and B being the main binding screws. One of the cores x x is stationary, the other one y y turns upon screw points r; both of these cores are provided with pole pieces, which face each other as shown in the figure. The contact arm z is rigidly attached to the movable core y y, and serves to open and close the local circuit at the contact screws k k', the former being insulated. The adjusting screw g regulates the tension of the relay spring. C and D are the local connections.

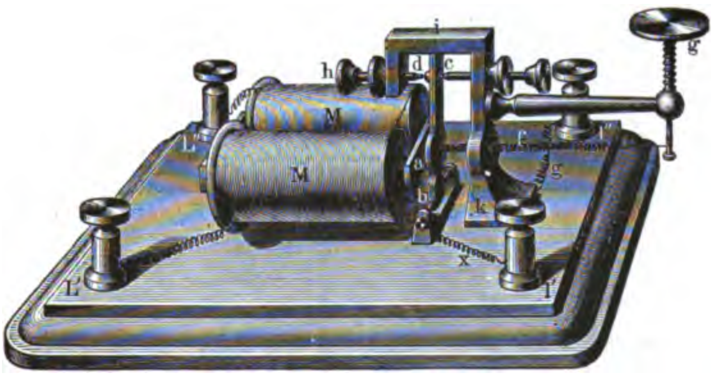


Fig. 280.

The form shown in fig. 280 is known as the American relay, and is so nearly identical in principle and construction with some of those which have been already described as to require no further explanation.

A plan or top view of Siemens and Halske's box relay is given in fig. 281. This arrangement is much liked, owing to its sensitiveness and convenience of adjustment. The poles of the electro-magnet terminate in rectangular pole pieces m m'. The terminal wires of the helices are attached to the binding screws x y. The soft iron lever or armature d turns upon a pivot in

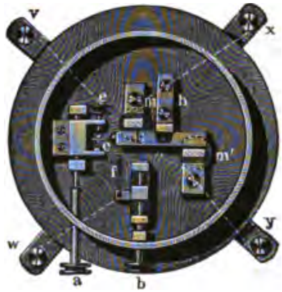


Fig 281.

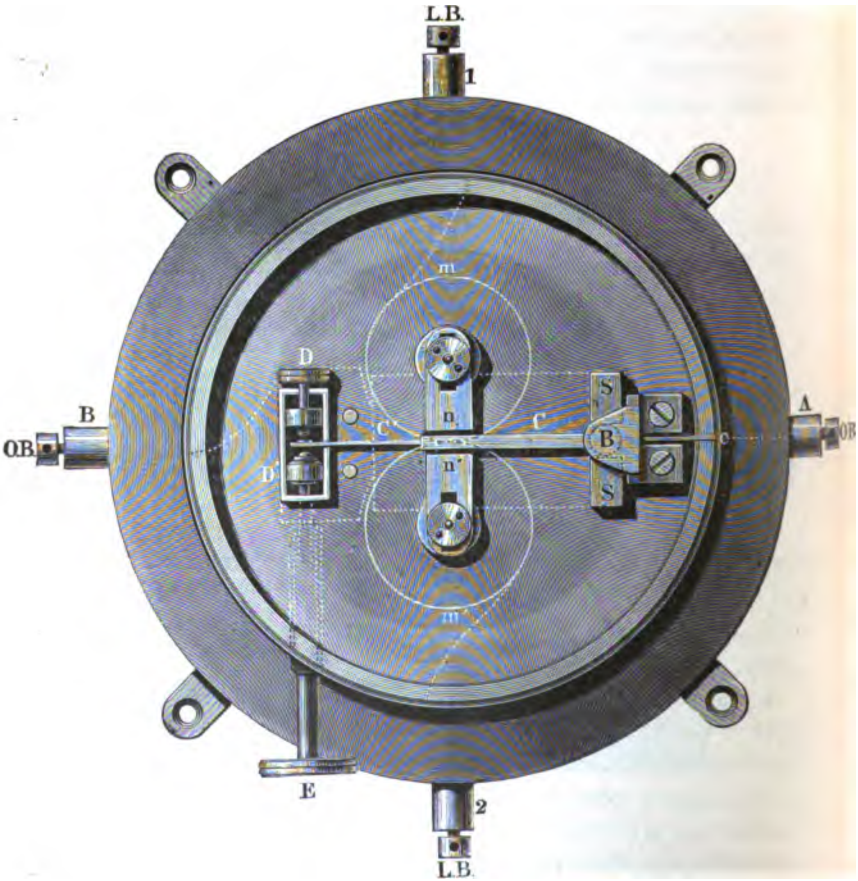


Fig. 282.

the end of the bracket or support *h*. The tension of the retracting spring *f* is regulated by means of the screw *b*. The working contact *e* and the insulated resting contact *e'* are mounted upon a carriage which is movable by means of the screw *a*, so that the distance of the armature from the poles may be adjusted; a result which is accomplished in the American instrument by rendering the electro-magnet itself movable. The play of the armature is regulated by the screw *e*, which forms the resting contact. The local wires are attached at *v* and *w*, the connections within the instrument being shown in dotted lines. The machinery is covered by a circular piece of plate glass, set in the top, which protects the parts from dust, and for this reason the relay usually works in a very satisfactory manner.

SIEMENS'S POLARIZED RELAY.

This instrument is in general use in England, and in many countries on the continent of Europe, and is regarded as an improvement on the ordinary Morse relay, particularly as it does not require any adjustable spring as a retractile force.

Fig. 282 represents a plan view of this instrument, and fig. 283 the same in vertical section through the centre.

The relay consists of a steel magnet N S, bent to a right angle, fig. 283, on whose leg N the soft iron cores *n n'* and the wire coils or helices *m m'* of an electro-magnet are fixed, whilst at the extreme end of the other leg S is a small soft iron bar *c c'*, which operates as a relay lever and armature, turning horizontally on its pivot B. The motion of this armature is limited by the metallic screw D on the one side, and by the agate stud D' on the other. (See fig. 282).

Fig. 284 represents the steel magnet N S more in detail.

On the leg of this magnet the iron coils *n n'* are attached, upon which the coils *m m'* are wound. The south pole S polarizes the tongue *c c'*.

Fig. 285 represents the electro-magnet *m m'*, the steel magnet N S S, and the polarized tongue *c c'*, in perspective.

As soft iron, when placed in contact with the pole of a mag-

net, becomes itself magnetized, and takes the same polarity as the pole with which it is connected, it follows that when N and S, fig. 283, represent the north and south poles of the steel mag

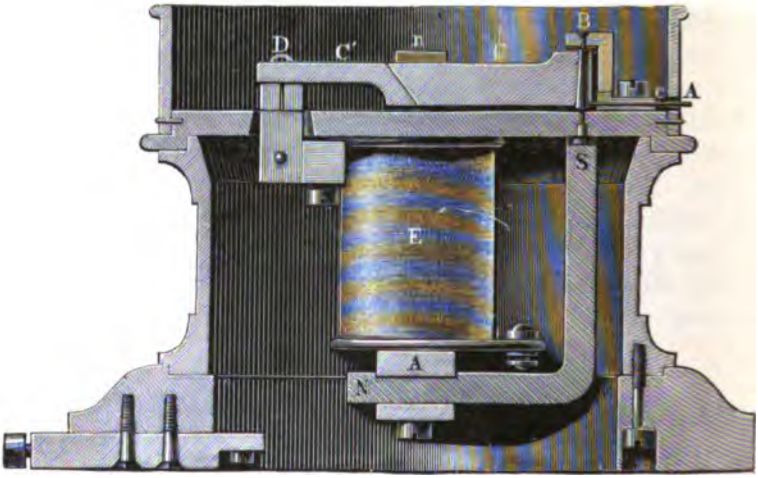


Fig. 283.

net, then the upper ends n n' of the iron core standing on the north pole N likewise form permanent north poles, and for the same reason the extreme end c' of the armature c c', which at

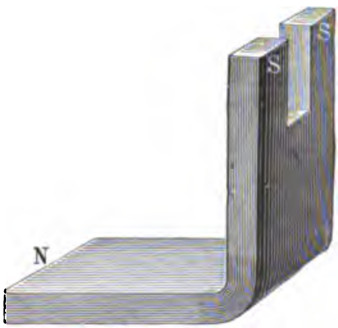


Fig 284.

Fig 285.

S stands on a south pole, permanently a south pole. Therefore the armature will be attracted equally by north poles n and n', but if it be brought nearer to one than the other it will be held

there, because it is under the influence of a more powerful force. If the attraction between n and C′ predominates, the armature lever will lie against the point D, and if the attraction is greater between n' and C′ it will rest on the agate point D′. It is evident that the latter position, where the local battery, which is put in between A and B, is open, corresponds with the position of rest of the ordinary relay.

When the key is closed at the remote station, and a line current is sent through the coils m m', one of the poles n n' becomes oppositely polarized. Suppose that this current causes at n a north pole, and at n' a south pole, then the north magnetism already at n is increased, but destroyed at n'.

As the south magnetism at c is, however, unchanged, the attraction of n toward c' is predominant, and the tongue of the lever c c' strikes against the contact screw D, and closes the local circuit.

When the line current ceases the lever still remains in contact with screw D, as then the electro-magnetism from m m' of course disappears, but the attraction between C and n continues predominant on account of its being nearer.

The return of the armature C C′ to its former position can only be effected by a reverse current, which is produced at the remote station by a pole-changing key, the south magnetism being produced at m, and north magnetism at m', by which the north magnetism already to be found at n is decreased and strengthened at n', consequently the former attraction between n and C′ is destroyed, and, on the contrary, the attraction between n' and C′ predominates. The tongue C C′ thus again strikes against the insulating point D′ and interrupts the local circuit, whose poles are connected with A and B, and by it further with C C′ and D.

No adjustment of the armature lever is required after it has been properly placed by means of the regulating screw E, no matter which pole of the battery is to line, and thus the use of a spring as a retractile force is entirely dispensed with.

It is obvious that the polarized relay can be very advantage-

ously used likewise for ordinary battery currents of one direction. For this purpose it is only required that the movable pole pieces n n' shall be placed at different distances from the polarized tongues C C′. The piece n', which corresponds to the rest or D′ side, must be placed nearer to the tongue C C′ than piece n. In this case, as long as no current passes through m m' the attraction of the north pole n', by the south polarized tongue C′, increases that of the north pole n, and consequently the armature C′ is constantly attracted by n', and the tongue C′ remains against the insulated point D′ and interrupts the local circuit. When, however, a line current arrives of such a polarity as to form at m a north pole, and at m' a south pole, then the north magnetism already present at n is increased, and the south magnetism present at n' destroyed or replaced by south magnetism, so that the attraction of n and C′ predominates, and, accordingly, the tongue C C′ is drawn over to the opposite side and closes the local battery at D. It is true that with the breaking of the line current the magnetism at m and m' again ceases, but the north magnetism at n and n' caused by the steel magnet N S remains, and, consequently, the tongue at n should remain in the same position; but as the space for motion between D and D′ is very small, only a little change is made in the distance of the tongue from n and n' on account of its movement towards n, and it has thus, just as before, on account of its position, a little more attraction for n' than for n. As, therefore, C′ stands nearer to n' than to n, the attraction of n' predominates and attracts the tongue C′ back again, thus again interrupting the local battery until a new line current closes it.

The polarized relay is exceedingly sensitive on account of the absence of the retracting spring, which the electro-magnet is not obliged to overcome, and also because the action of the poles n and n' on the armature C C′ is a double one, attracting and repelling at the same time. As no regulation of the adjustment is required to meet the varying strengths of the line current, this relay is greatly preferred to the ordinary form, and it is very generally employed all over Europe.

To adjust the polarized relay, place the pole pieces n and n' at a convenient distance apart, and then turn the screw B until the tongue b is brought as nearly as possible in the centre between the poles, so as to have equal room for adjustment on each side. The set-screw D is then adjusted so that the motion of the tongue or armature lever shall be about one-twentieth of an inch between the insulated stud D′ and the contact point. The adjusting screw E is then turned so that the armature, when no current is flowing, shall be slightly attracted by the pole, bringing the tongue into contact with the agate point D′. If, after the instrument is so adjusted, the armature lever remains permanently in contact with the circuit closing point D when the distant station is sending, turn screw E to the right, so as to lessen the attraction of n and increase that of n'. If this produces no effect, either place n a little farther from, or n' a little more to the tongue or armature lever C′ C, until the desired result is obtained.

Sometimes this relay is combined with a galvanoscope, the same currents working both. On the top of the glass cover of the relay, under a small glass dome, is a single needle supported upon a point. When a current passes through the coils of the relay the polarization of the electro-magnet cores is altered and the needle deflected. The operator who is receiving can therefore see when currents are arriving through the relay without employing a separate galvanoscope.

This relay was originally devised for the purpose of working in connection with the magneto-induction key described on page 503, but the principle has proved so valuable that it is now extensively used for all varieties of double current and even single current working.

THE DIRECT WORKING POLARIZED INK-WRITER.

The original direct working polarized ink-writer of Siemens and Halske, fig. 286, is based upon the principle of the polarized relay, the devices for marking the paper being similar in principle to those of John and Digney. The arrangement of the clock-work and mainspring within the case is similar in all re-

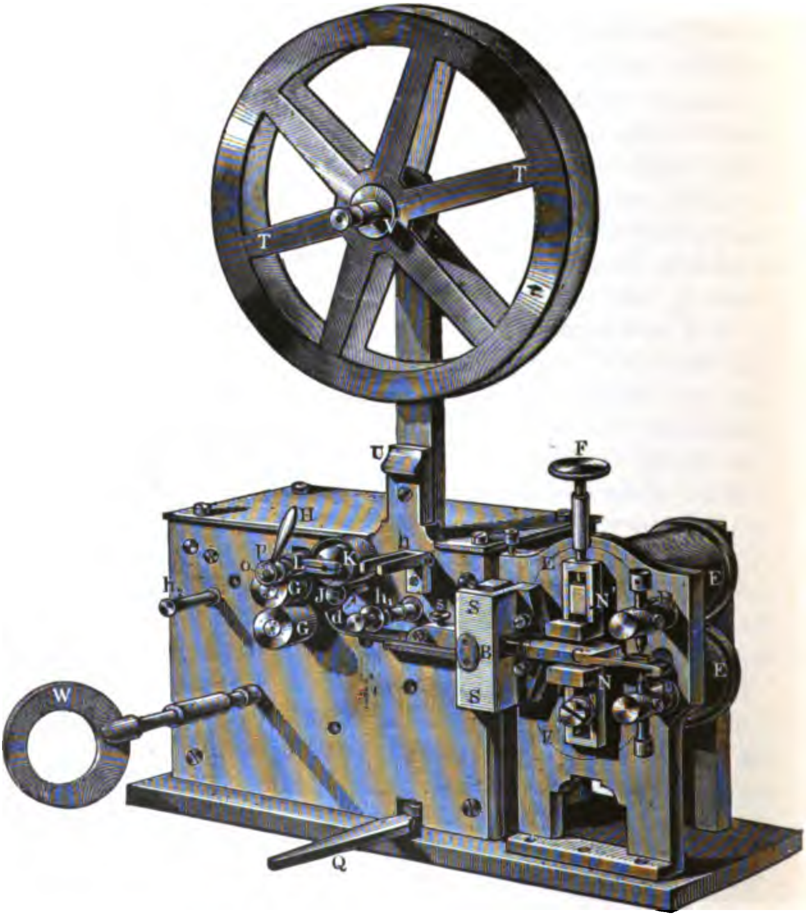


Fig. 286.

spects to that of the instruments previously described. The printing wheel J is turned by the clock-work and receives its ink from the felt roller K, which rests upon it, and turns with it by friction. G G_1 are the paper rollers, which draw the strip from the reel T, underneath the printing wheel J, against which it is pressed whenever the end of the printing lever *d* is raised; the whole process, as far as marking the paper is concerned, being almost precisely like that employed in the Digney apparatus. The electro-magnet is arranged exactly like that of a Siemens polarized relay. The coils of the magnet E E_1 are placed horizontally one above the other. At the back of the instrument the electro-magnet is secured by its yoke to the north pole of an angularly bent permanent magnet of considerable power, whose south end is brought round so as to project from the front of the instrument, as shown at S S_1. The polarized tongue or armature C C_1 of soft iron, is pivoted at B, within a slot cut in the south pole S S of the permanent magnet, and its opposite end is free to vibrate between the angular soft iron pole-pieces N N_1 of the electro-magnet E E, the stroke of the armature being limited by the upper and lower adjustable screw stops D D. Attached to the lever C C is the writing spring *d*, bent upwards, as shown in the figure, and capable of a slight adjustment by means of the screw *s*.

To operate this instrument a pole-changing key is required, the dots and dashes being sent by a current of one polarity, usually positive, and the spaces by a negative current instead of a break. This dispensed altogether with the retracting spring and renders the instrument practically self-adjusting. When the main current is strong the pole-pieces N and N_1 are adjusted at a greater distance from the tongue C than when it is weak. This adjustment is effected by means of the screw F.

If a positive current passes through the electro-magnet E E_1 its effect is to increase the north magnetism already existing in the pole N, and to diminish or neutralize entirely that already existing in the pole N_1. Hence the tongue or armature is attracted to the pole N; the spring arm *d* is lifted and presses

the moving strip of paper against the sharp edge of the inked printing wheel J. When the current is reversed to form a space between two successive signals, the pole N_1 in turn becomes the most powerful, the tongue C is attracted upward, and the pressure of the spring arm *d* removed from the paper strip. The apparatus will also operate as well with the polarized as with the ordinary electro-magnet when the currents are in one direction only, but it is preferable to use the reversals, especially when the circuits are long or badly insulated. Whenever necessary the apparatus is arranged with a self-starter and with an alarm bell.

More recently an improved construction of the direct working polarized ink-writer (fig. 287) has been devised by Siemens and Halske, which is unquestionably the most perfect apparatus of the kind, in every respect, that has yet been produced. The improvements in this instrument relate entirely to the writing apparatus, the arrangement of the polarized magnet and the tongue being identical with that in fig. 286, and the same letters of reference indicating like parts. The axis of the printing wheel J is provided with a swivel, as in fig. 256, and turns with its lower half in the ink reservoir L, which is supplied through the cover *l*. The paper runs from the reel T, around the guide pulleys 1, 2, 3, 4, and thence between the paper rollers G and G_1, and out over the guide 6. In all other respects the operation of the instrument is the same as that described in the preceding paragraph.

The great advantages of the direct working polarized ink-writer over any other form of Morse recording apparatus may be summed up as follows:

1. The instrument is worked by a main current of moderate strength, dispensing altogether with relays and local batteries, thus simplifying the equipment of an office in a marked degree, and increasing the reliability of working.

2. The instrument may be set up without reference to the direction in which the light falls upon it, which is not the case with the embossing register.

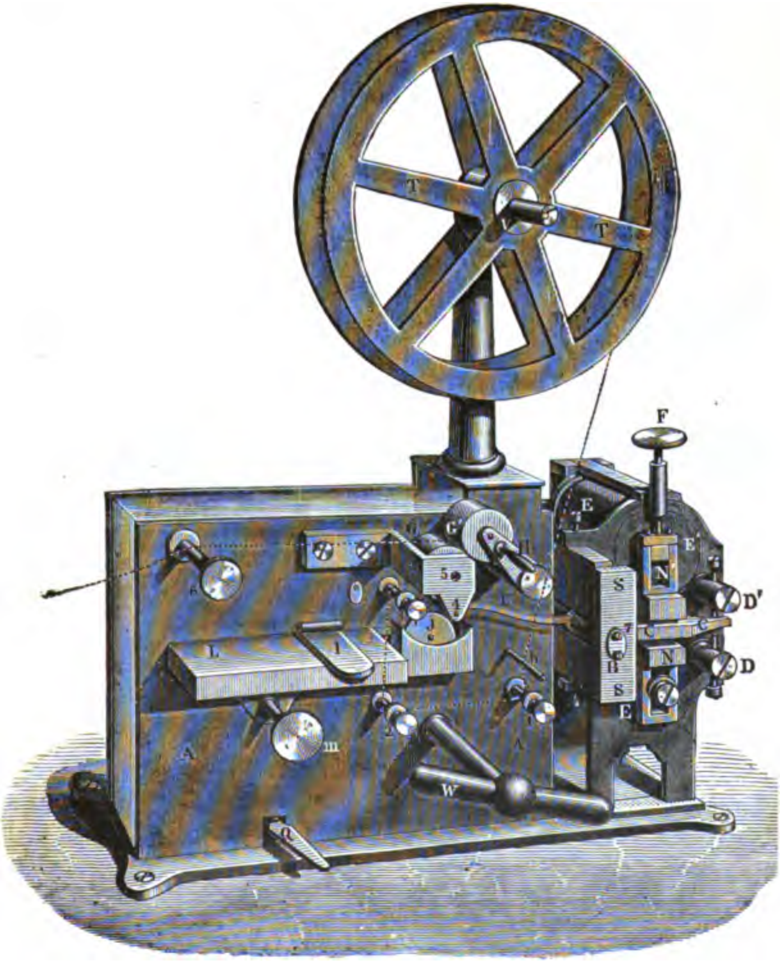


Fig. 287.

3. The supply of ink is uniform, and the marks upon the paper invariably distinct and perfect.

4. The movement of the printing wheel need not exceed the ordinary movement of the armature of a relay.

5. The apparatus is so arranged that an excess of ink cannot blot the paper, nor soil the machinery. The reservoir is of sufficient capacity to hold a large supply of ink, and when needed may be filled without inconvenience or loss of time.

These advantages are so apparent that the improved polarized ink-writer is rapidly superseding the older forms in all parts of

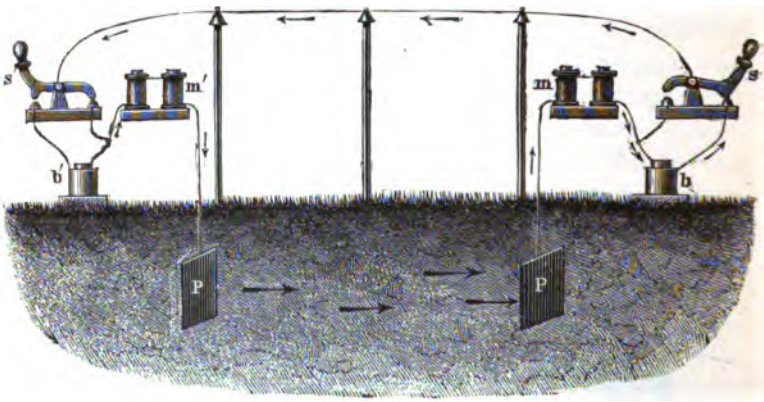


Fig. 288.

Europe, Asia, and South America. Large numbers of them are employed on the government telegraph lines in England and India, although of late years there seems to be a tendency in the last named countries to introduce the system of sound reading which has proved so successful in America.

EUROPEAN TELEGRAPHIC CIRCUITS.

As we have before stated, the European telegraphs are usually arranged upon what is termed the open circuit plan. The principle of the single current, usually known in Europe as the German system, is illustrated in fig. 288, which represents two

terminal stations with main line instruments, that is, without relays. The electro-magnets of the receiving instruments are shown at *m m′*; *s s′* are the keys, provided with rear contacts, as shown in fig. 265; *b b′* are the main batteries, and P P′ the earth plates. When both keys are open, as shown at *s′*, no current traverses the line, because one pole of each battery, being connected to the front contact of its corresponding key, is open at that point. Thus both batteries are open when the line is not in use. But if the key at one of the stations is depressed, as at *s* in the figure, then the battery *b* at this station is connected with the line. The current traverses the line in the direction of the

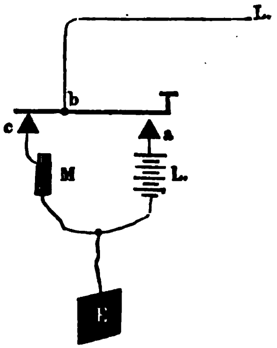


Fig. 289.

arrows, passing through the rear contact of the key *s′*, and thence through the helices of the instrument *m′* to the earth at P′. The return current passes from the earth at P through the instrument *m* at the sending station, and so to the other pole of the battery *b*. Thus both instruments are operated when either or both keys are depressed. Fig. 289 shows the usual conventional method of representing the key, battery, instrument M, etc., in diagrams of apparatus and connections. It will be noticed in this instance, however, that the instrument is inserted between the rear contact of the key and the junction of the battery and earth wires. This is the arrangement now generally preferred instead of that shown in the preceding figure. The outgoing current passes

around the sender's own instrument instead of through it, and thus its resistance is removed from the circuit, often a great advantage, while the depression of the receiving operator's key at any moment will set it in action, thus serving the purpose of stopping the sending operator at pleasure, if a word is not understood.

Where two terminal stations work by the aid of relays, the usual arrangement is that shown in the diagram, fig. 290, which represents the position of the various parts of the Morse apparatus, which, as used on all the government lines of the German-

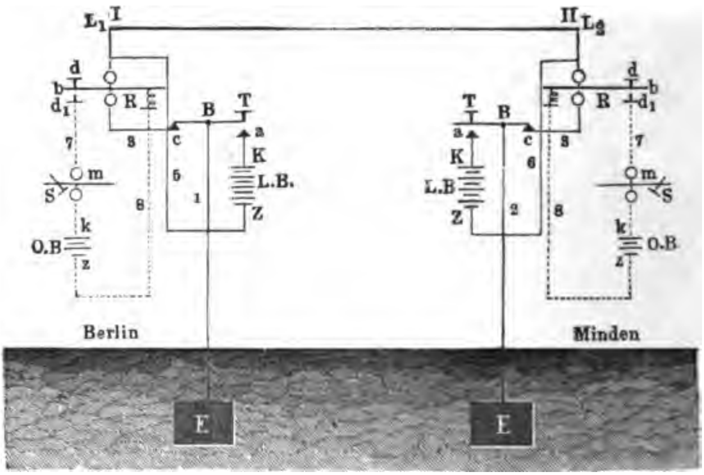


Fig. 290.

Austrian Union, as well as in Switzerland, France, Great Britain and India, consists of the following batteries and apparatus at each station: One main and one local battery, a relay, register, key and galvanometer. The main line and connections are represented by continuous lines, the local connections by the dotted lines in the diagram.

When the line is idle the keys T T at both stations are open, as shown in the figure, the line is consequently connected to earth through the back contact, and no current goes out from the batteries.

If the operator at station I. wishes to communicate with station II., he simply depresses his key and transmits the proper call. For each depression a current flows to the line around the relay at the sending end, traverses the relay at the distant station, and thence passes through the back contact of the key to the earth.

The relay at station II. is consequently set in action and closes its own local circuit in which the register is placed. The operator whose attention is thus called signifies his readiness to receive, releases the clock-work of his instrument, and by this means

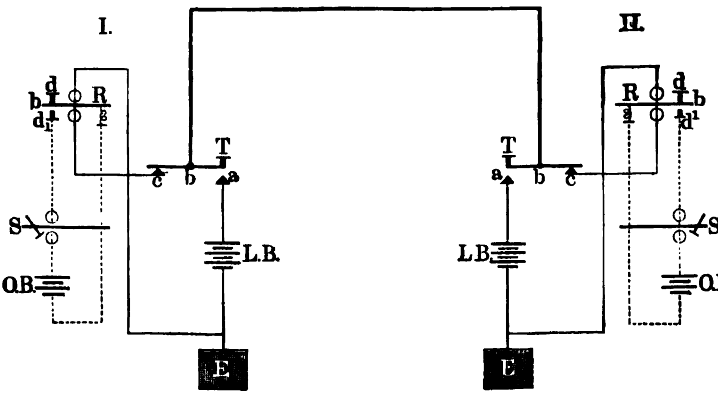


Fig. 291.

starts the paper on which the communication is recorded. After acknowledging receipt of the message he then transmits in turn any business which he may have on hand.

It is sometimes desirable to connect the line directly with the key lever and the relay to earth instead of the reverse, as in the ordinary manner. Fig. 291 shows this method of connecting the apparatus.

On many of the German railway lines a closed circuit system is used, resembling in general principle that used in America, except that the signals are made by breaking instead of closing the circuit. The manner in which the Morse apparatus is

arranged, with rear contact points for working by the interruption of a closed circuit, is as follows:

Fig. 292 represents the connections of the apparatus at two terminal stations. T is the key with back closing points *c*, instead of front, as ordinarily arranged; R the relay; S the recording apparatus; L B the line battery, and O B the local battery. So long as the keys are not depressed the currents from both line batteries circulate through the line and relays, consequently all the relay armatures are attracted; by this means all the armature levers are made to press against the insu-

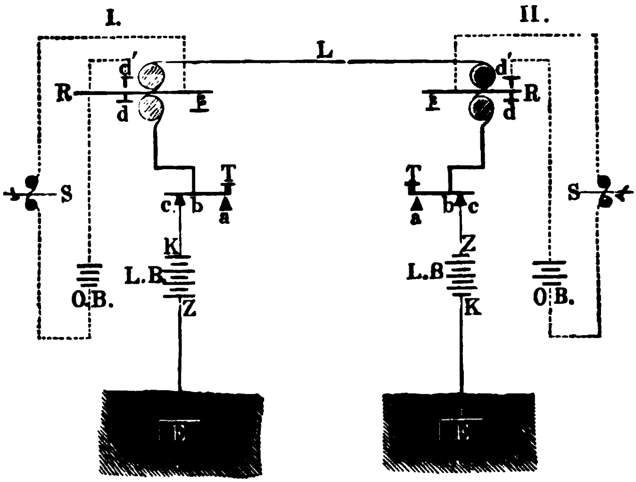


Fig. 292.

lated stops in front, and the local batteries are kept open, which, it will be seen, is precisely the reverse of the American system described in the preceding chapter.

When a key is depressed at I., for instance, the line current is interrupted, the relay levers accordingly obey the retractile force of the springs and fall back against the local contact points; this closes the local battery and causes the current to circulate in the electro-magnets of the recording apparatus; this, in turn, actuates the marking points. It is obvious that a number of similar sets of apparatus may be placed at intermediate stations along

the line, as in the American system, and that no intermediate main batteries will be required, those at the terminal station being sufficient.

It will be seen from the two preceding paragraphs that the different action of the recording levers in the open and closed circuits consists in the fact that in the former case the relay armature is attracted when the key is depressed, in the latter when it is released; but each of these movements should give the proper Morse signals, consequently the writing lever must be arranged in a different manner in reference to the paper when the recording apparatus is worked direct in the main cir-

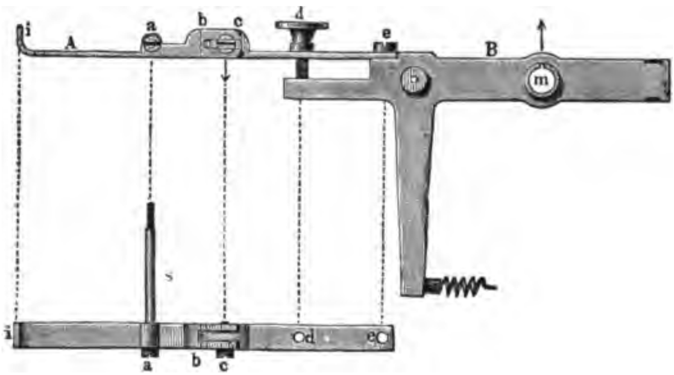


Fig. 293.

cuit if it is required to meet the requirements of the two cases. Now, it is quite possible to do this, but it is desirable, for several practical reasons, to make no alteration in the general arrangement of the apparatus, and to modify only the end of the pen-lever. For this reason the pen-lever should be so constructed that a simple and quickly performed operation will be sufficient to adapt it to either case at pleasure.

An ingenious arrangement of this kind, which is used in some of the German instruments, is illustrated in fig. 293. The writing lever consists of two parts, A and B, as shown both in side elevation and in plan in the figure. The armature *m* and

the retracting spring are attached to the lever B in the usual manner. The supplementary lever A turns upon an axis *a*, attached to the frame of the apparatus. The left hand end *i* is bent up into a knife edge, which serves to press the paper against the marking wheel, as in fig. 254, while the opposite end *b* is jointed at *c* to an arm *c e*, adjustable by means of the screw *d*, and attached to the lever B. By removing the compound lever. and attaching a straight arm to the lever B by means of the screws *d* and *e*, the action of the armature upon the marking wheel may be made direct instead of reverse. Where the relay is used the same result might, however, be attained with less trouble by reversing the contact points which serve to close the local circuit. The arms of the writing lever are of such length, in the above arrangement, that the stops need not be readjusted in making the change from the open to the closed circuit system, or *vice versa.*

The device just described, although very serviceable, requires some little time to change from one system to the other. An improvement was subsequently made, which consists simply in removing the steel pin from *a* and placing it in *b*, or the reverse, as the case may be.

A form of recording lever has been suggested for the ink-writer of Digney and Siemens, when these instruments are intended for both open and closed circuits, which is greatly to be commended for its extreme simplicity; it has, consequently, been very generally adopted.

This, as represented in figs. 294 and 295, consists of two parts: the ordinary armature lever B with its armature, retracting spring and elastic extension, and a supplementary double armed lever. Fig. 294 represents the form as arranged for the Digney instrument, and fig. 295 the arrangement for the Siemens instrument. The writing lever proper *i a b* is from two and a quarter to two and a half inches long, and at about two-thirds of its length from the marking wheel, turns on a pivot *a* projecting from the frame of the instrument.

The prolongation of the armature lever *c* has a fork-shaped

termination with unequal prongs, the relation of which to the pen lever is adjustable within narrow limits by means of the screw *d*.

Fig. 294 represents the position of the lever when arranged to work in the ordinary manner, by closing the circuit. When the key is depressed the armature is attracted, *g* and consequently *i* are carried upward, the paper ribbon is thus pressed against the marking wheel and records a signal. Fig. 295, on

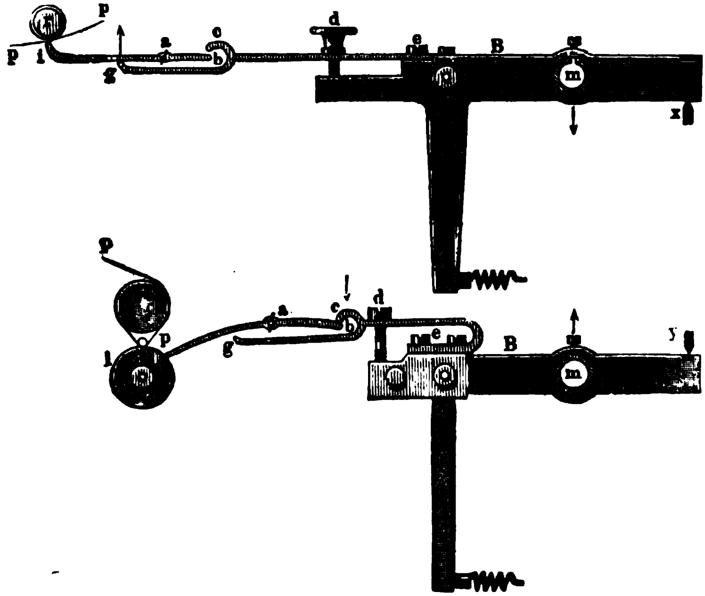


Fig. 294. *Fig.* 295.

the contrary, represents the position of the lever as arranged to work by opening the circuit. When the armature is released by depressing the key, the end *c* of the fork goes down and depresses the lever arm *a b*. The ink-wheel *i* is consequently carried against the paper band *p* and makes a signal, as in the other system.

The apparatus is quickly adapted to either mode of working. If it is to be worked in a closed circuit the armature B, fig. 294,

is pressed against the stop x and the screw d turned in such a manner that the end g presses the arm i and consequently the paper also, against the marking wheel. If, on the other hand, we wish to work by interrupting the circuit, the screw d is again turned, but in such a way that the end c of the fork acts on the lever arm b when the armature is released, so that the

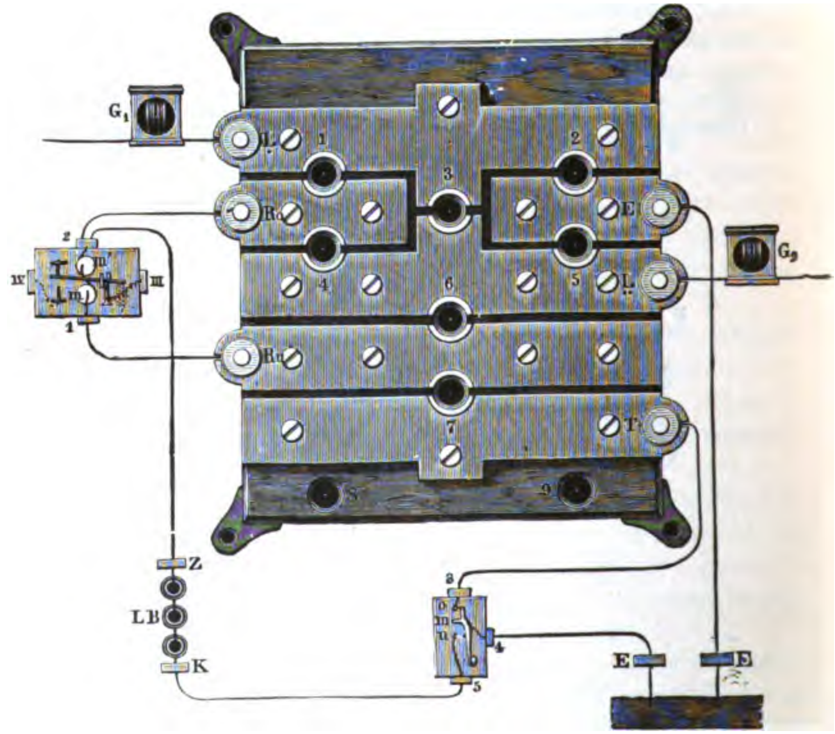


Fig. 296.

paper is carried against the marking wheel as before. One half to a full turn of the screw d is sufficient to change from either system to the other. We have before stated that the ink-writer, especially the polarized ink-writer of Siemens and Halske, requires but a slight force to operate it, consequently, when these instruments are used, a relay is seldom required.

It may be remarked, however, that in order to actuate the electro-magnet of the register by the line current, it is necessary in such cases to re-wind the soft iron cores with helices composed of many convolutions of fine wire; for example, about 8,500 feet, or 2,000 convolutions of No. 36 insulated copper wire, the resistance of which is usually about 1,500 ohms.

ARRANGEMENT OF APPARATUS AT WAY STATIONS.

Besides the main stations at the terminals of a long line, it is usually necessary to establish way stations along the route. If the method referred to on page 320 were generally adopted, each intermediate station would require two sets of apparatus, one for communicating in each direction, and a message to be transmitted from one terminal station to the other would have to be repeated at each of the intermediate offices; this would result not only in serious loss of time but subject the message also to unnecessary chances of error.

In order to overcome this evil, various arrangements have been devised, by means of which direct communication may be established between any two stations.

Nottebohm's plug commutator was devised to meet this want, and at one time was very extensively used. It consists, as represented in fig. 296, of six brass pieces fastened to a board. Between these holes are made for the insertion of a metallic plug, fig. 297, which serves to connect any two contiguous parts together. There are also two holes, 8 and 9, in the wooden frame, into which the plugs not required for immediate use may be placed, the arrangement being quite similar to that of the more recent American arrangement illustrated on page 453.

Fig. 297.

One end of the line wire is connected to the binding post L, the other to the post $\ddot{L}$. From the binding post E a wire connects directly with the ground. G_1 and G_2 are two vertical galvanometers. R*o* is connected to one end of the relay coil at 2; R*u* to the opposite end at 1.

The back contact of the key is connected to T, the lever to

earth, and the front contact to the positive pole of the main battery L B, whose negative pole is connected with the relay at 2. The local battery and connections are not represented.

For direct communication the Morse apparatus at an intermediate station is cut out altogether. This is done by inserting a plug at 3. The transmission of messages between the terminal stations is then made apparent at the intermediate points by the constant oscillating movement of the vertical galvanometer needles. When the correspondence is finished the keys at the two corresponding stations are depressed a moment; this causes a constant deflection of the needles at the way stations, and is a signal for the operator to place his instrument in circuit again.

By plugging up 1 and 6, the instrument at the way station is included in circuit; this very frequently becomes necessary, for instance, when it is desired to leave drop copies at different points along the line.

When communication is made between a way station and any other station on the right, plugs must be placed in 2, 4 and 7. If, now, a station on the left calls, the needle of galvanometer will be deflected. This should be observed by the operator, who will then put a plug in 1 and ascertain what is wanted. If the case is urgent, preference is given to the station on the left.

When the holes 1, 7 and 5 are plugged, the way station is in working communication with the stations on the left. The operator will also be notified by G_2 in case any station at the right wishes to communicate with him.

The manner of connecting up at terminal stations is exactly the same as that shown in fig. 290.

The use of the commutator just described was attended with much inconvenience, and consequently it was soon replaced by the more perfect one of Siemens and Halske, which, with some modifications of form, has since been very extensively used. It consists of three heavy pieces of brass fastened to an insulating base, as represented in fig. 298, which also shows the various connections. As may be readily seen, all of the different changes noticed above may be quickly made with this switch,

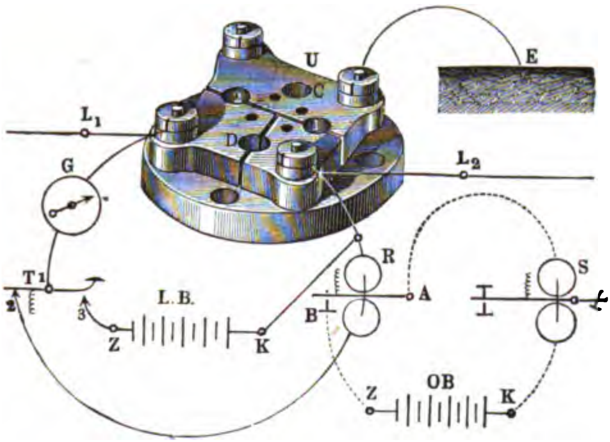


Fig. 298.

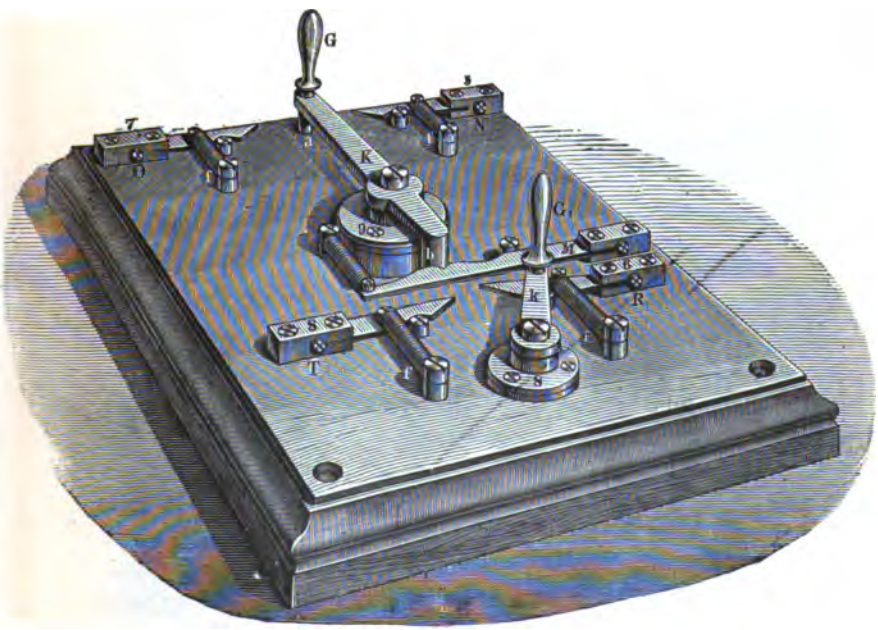


Fig. 299.

while the way station is also enabled to transmit to stations situated on opposite sides of it at the same time.

The form of switch for way stations, represented in fig. 299, is also used to a considerable extent. When properly constructed it is a safe and convenient one, and well adapted to the purpose for which it is designed. K and *k* are two levers or switch arms, the largest of which is permanently connected to earth as represented in fig. 300. M, N, O, R, T are five brass arms which are pressed firmly against metallic stops by the spiral springs *f*. In its normal position the arm K stands between N and O with the end *b* in a notch of the brass strip M. When the smaller arm *k* is placed on T the instrument is in circuit; when turned on R the instrument is cut out. Direct communication between the way station and a station on the right or left is made by turning the switch K to O or N respectively, as the case may be. Fig. 300 shows this form of switch as arranged in connection with the key, relay, register and galvanometers for use at a way station, the main wires being shown as usual in full lines, and the local wires in dotted lines. The letters and numerals of reference correspond with those of fig. 299, and the manner in which the connections are made will be readily understood from the figure without further explanation.

In order that way stations may be enabled to correspond in both directions independently, they are usually provided with two sets of instruments. The switching is then somewhat simplified. Figs. 301 and 302 represent a switch and the necessary office connections for two sets of instruments. L_1 and L_2 are the main lines in each direction, which pass through the galvanometers G_1 and G_2 directly to the switch. When a plug is placed in the switch at 1, the lines are connected directly through outside of the apparatus, but with the galvanometers in circuit. By changing the plug from 1 to 2 the line is divided and both sides put to earth through the respective instruments. Thus a current arriving by line L_1 passes through G_1 and thence by way of 3, 8, to the lever *b* and back contact *c* of key T_1, thence by wire 9 to relay R_1, wire 10 and plug 2 to the earth, at P. The arriv-

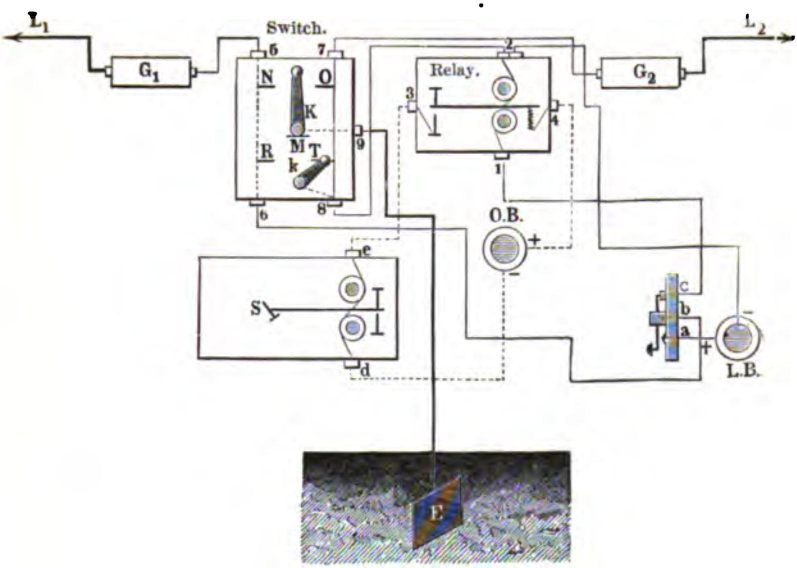


Fig. 300.

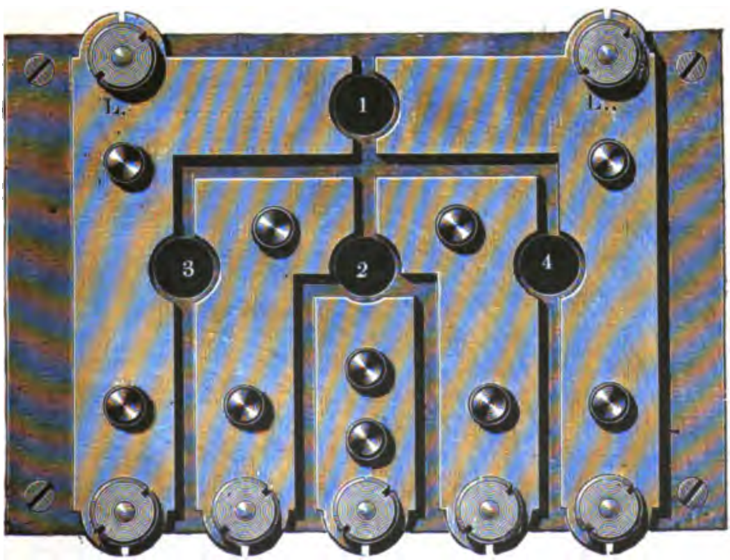


Fig. 301.

ing currents by the line L_2 pursue a corresponding course, reaching the earth wire also at plug 2. When either of the keys T_1 or T_2 are depressed, the positive pole of the line battery is connected to the line through the front contact *a* and wires 7 or

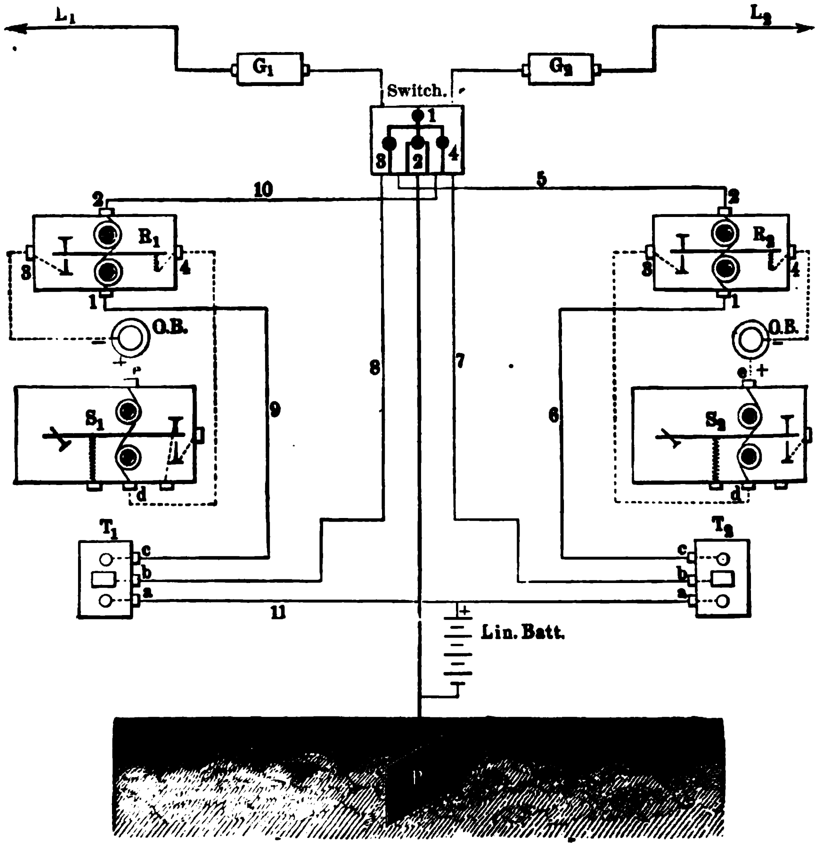


Fig. 302.

8. The local connections of the registers S_1 and S_2 with the relays R_1 and R_2 and the local batteries OB, are indicated in dotted lines.

The same combination is sometimes arranged to work the

separate recorders with a single local battery instead of two, as in the preceding case.

A simple and inexpensive switch has also been devised for stations where there are three or more lines. This is represented in fig. 303, and will be readily understood without further explanation. Fig. 304 shows the various office connections. The three lines are represented by L^{I}, L^{II} and L^{III}. An instru-

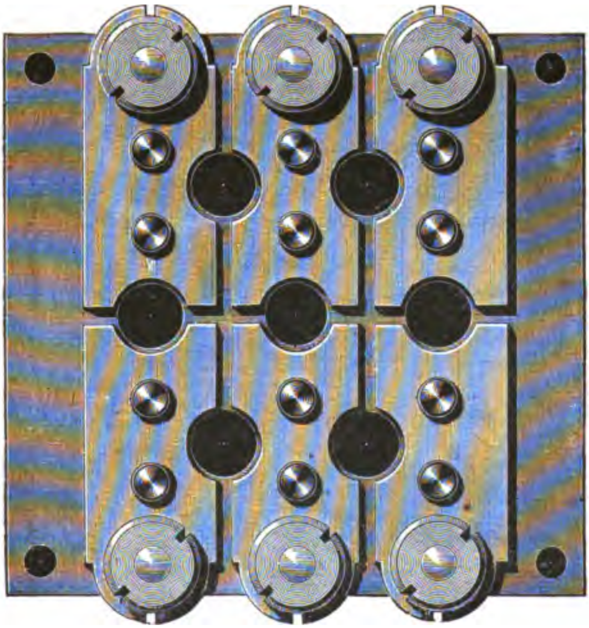


Fig. 303.

ment termed the "circular apparatus," which may be a galvanometer, relay or call-bell, is employed to receive calls on whichever line is not at the moment in use. B represents the main battery. The small diagrams at the side of the figure, numbered 1, 2 and 3, represent the switch, with the plugs in various positions. In No. 1, lines L^{I} and L^{II} are connected through the circular apparatus, and line L^{III} to the station instruments. In No. 2, lines L^{I} and L^{III}, and in No. 3, lines

L^{II} and L^{III} are connected through, the remaining one being connected to the station instruments.

At stations where there are four different lines, and where it frequently becomes necessary to connect for through communication, it is best to have as many separate sets of instruments, in order to avoid the loss of time that would otherwise result when notifying the stations cut off that the line has been divided. Fig. 305 shows the arrangement for such cases.

Fig. 306 is a switch similar in its principle and in its application to the one already described and illustrated in fig. 238. It

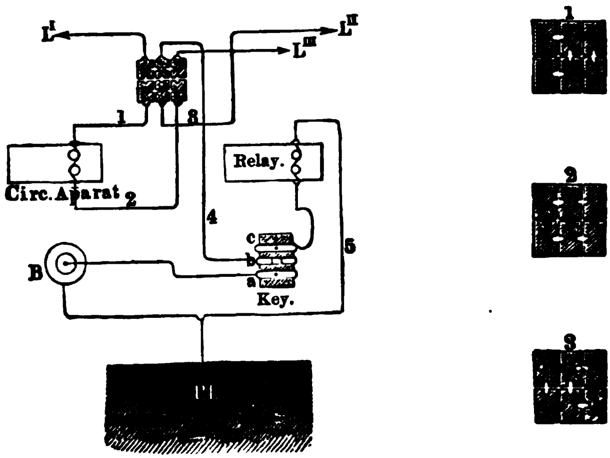


Fig. 304.

is known in Europe as the Swiss commutator or universal switch. It is only employed in large terminal stations where a considerable number of wires converge. The line wires are connected with the binding screws numbered consecutively from 1 to 12, and the instruments to the screws attached to the transverse bars, which are numbered in a similar manner from I to XII. The split peg which is used for making the connections is shown at the bottom of the figure. Fig. 307 is termed a battery commutator, and is made use of in cases where a battery is required to be reversed in respect to the line. The two poles of the battery

are connected with *c* and *d*, while the wire *e*, which may represent either the line or an instrument, is connected with *a* and *b*. It is obvious that if the holes 1 and 2 are plugged, the current of the battery will pass through the wire *e* in one direction, while this direction will be reversed by shifting the pegs to 3 and 4. Fig. 308 is an arrangement by which either or both of two lines may be connected to the same battery at pleasure. The battery pole is connected to L, and L_1 L_2 are the respective

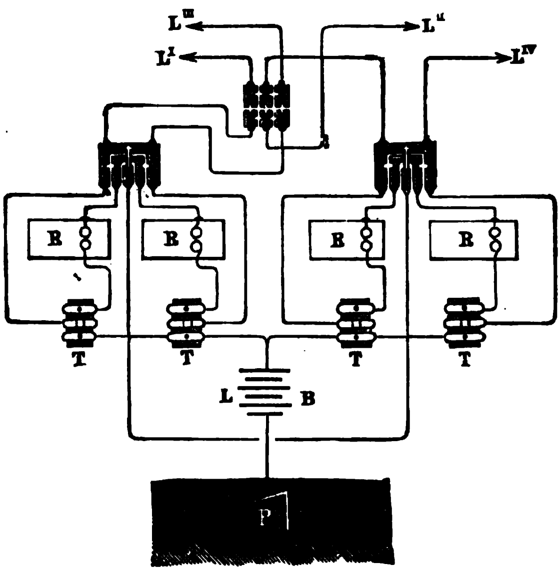


Fig. 305.

lines. The connections are made by inserting pegs in 1 and 2. These commutators are also employed for other purposes, as occasion demands.

WORKING BY CONTINUOUS CURRENTS WITH POLARIZED RELAYS.

The arrangement of the apparatus with polarized relays upon lines operated by a continuous current is such that the battery current traverses the line continually during the time in which

the key remains open or on its back contact. Fig. 309 represents the connection for a terminal station. When the key is depressed the current is interrupted and the lever of the polarized relay R falls back on the local contact point. This operates the register in the usual manner.

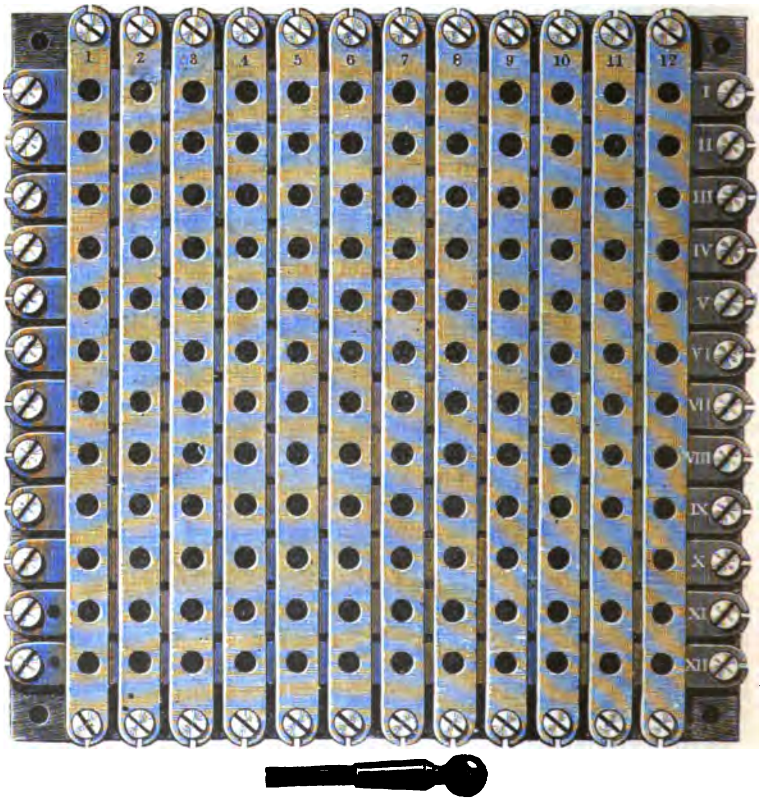


Fig 306.

The connections for a way station are represented in fig. 310, and will scarcely need any further description. Fig. 311 is another representation of the same system, embracing in one figure all the principal connections for one way and two terminal stations. Ordinary instead of polarized relays are shown in this

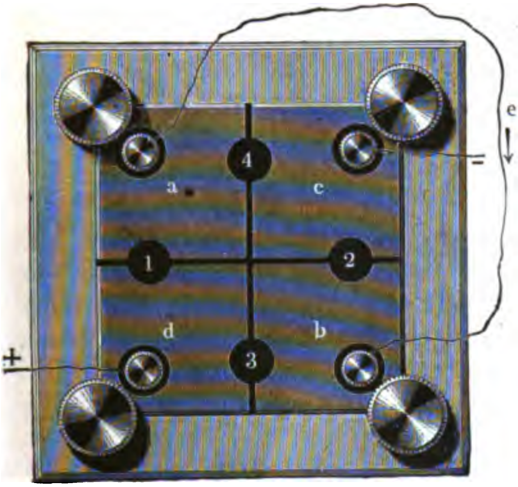


Fig. 307.

Fig. 308.

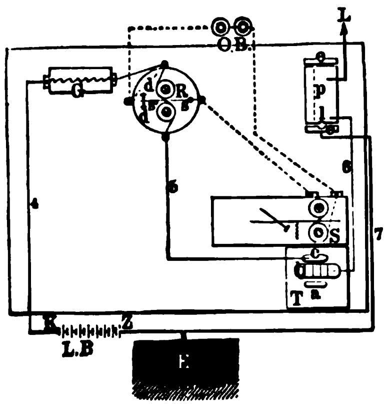


Fig. 309.

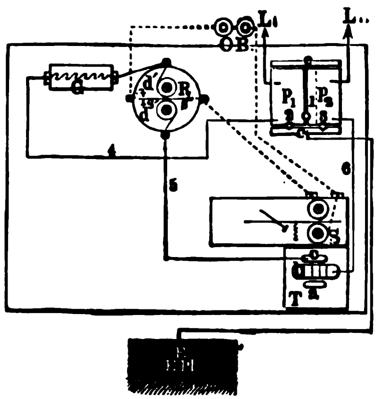


Fig. 310.

case. The system of working by a continuous current, which has been described, possesses some important advantages. The keys, as arranged, are self-closing, therefore the line cannot be left open by accident. Many of the South American lines are operated upon this plan, and it is also employed in the American fire-alarm telegraph.

WORKING THE MORSE SYSTEM BY INDUCED CURRENTS.

Siemens and Halske were the first to devise a system of telegraphing by induced currents. With this system no line batteries are required at any station, these being replaced by the momentary induced currents which arise every time that a

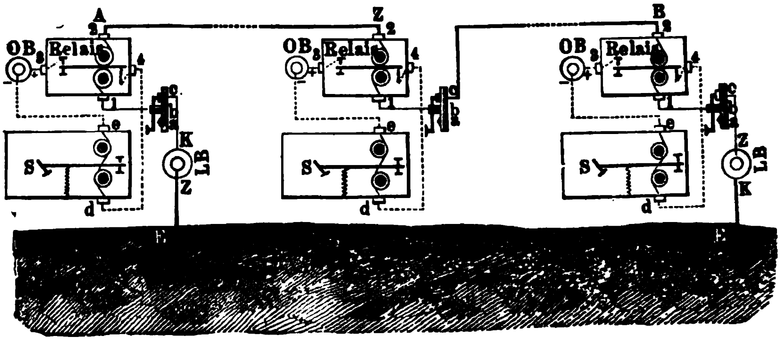


Fig. 311.

key is opened or closed. The principal apparatus at each station, as shown connected up in fig. 312, consists of an ordinary register S, a polarized relay R, an inductor J, for producing the induced currents, and a key T. The latter differs slightly from the ordinary key, in that it has one additional contact *a* (see fig. 271). When the key is depressed the main line circuit is first closed at *a*. The local circuit is closed immediately after at *b*.

The inductor J, fig. 313, consists of a hollow iron cylinder *e*, about 18 inches long and 2 inches in diameter. This is sawed through in the direction of its length and filled inside with soft

iron wires. A coil of coarse copper wire is then wound on the iron core, and another coil, containing many convolutions of fine wire, is placed over the first. One end of the inner coil is connected to the key lever, the other to the negative pole of the

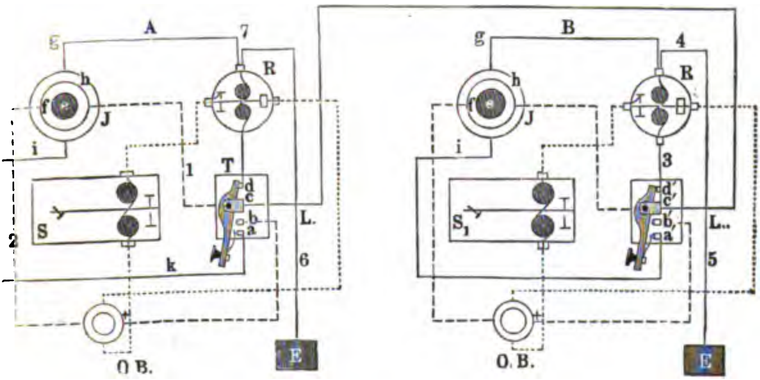


Fig. 312.

local battery O B, the positive pole being already connected to the contact *b* of the key. The secondary coil is joined by one of its ends to the relay and earth, by the other to the contact *a* of the key. By depressing the key the current from the local

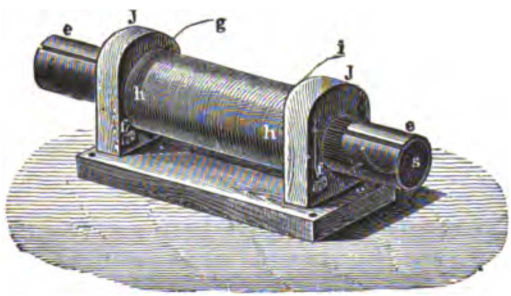


Fig. 313.

battery O B is caused to circulate in the primary coil of the induction apparatus, and the iron core becomes charged. An induced current is thus set up in the secondary coil which traverses the line and all the relays in circuit; by this means the

relay levers are thrown against the local contact points, circuit is closed, and the pen-levers mark. Although the secondary current lasts only a moment, it is sufficient to operate the relay levers; these once having been moved, are held by their own permanent magnetism firmly against the local points. When the key is opened an induced current of opposite polarity is sent to line and the levers return to the back contact. The same local battery is arranged to work both the register and the induction apparatus. It should be observed also that the spring contact on the key prevents the opening of the main circuit until after the local circuit, containing the primary coil of the inductor, is broken at *b*. From what has been said it will readily be seen that a system of working by induced currents possesses some important advantages. The line battery is done away with altogether, and in consequence of the comparatively high potential of the induced currents, any considerable line resistance is of less moment than in a system where the regular battery current is used. Moreover, as there are no relay springs to be overcome, a less powerful current is required to work the armature levers.

Magneto-electric currents may also be employed to operate the Morse system of telegraphy. We have already described the key which is employed for this purpose on pages 503 and 504. Fig. 314 is a diagram representing the arrangement of a line with two terminal stations, equipped with polarized ink-writers S_1 and S_2, and magneto-electric keys M_1 and M_2. If we suppose that station II. is to transmit to station I. and that the switch C_1 is open, as it is always supposed to be when the apparatus is at rest, the currents arriving at station I. will go by the way of L_1 and R, through the electro-magnet E of the polarized ink-writer S_1, thence by C_1 W A and H, through the body of the magneto-electric key, and finally by way of Q and E_1 to the earth. These currents therefore pass through the coils of the polarized electro-magnet E of the ink-writer (fig. 287), alternately in one direction and the other. The positive currents throw the writing spring *d* and the paper ribbon against

the printing wheel J, which marks the signs upon the paper; while the negative currents reverse the motion of the writing spring and paper and thus determine the length of the signals It will be observed that the arriving currents do not pass through the armature coils of the magneto-key.

If now, on the other hand, a communication is to be sent from I. to II., the switch C_1 should be placed on R. If then the lever H of the magneto-key is depressed or elevated, during the period occupied by each movement, the short circuit between H and A A, that is, between the line and the earth, is interrupted,

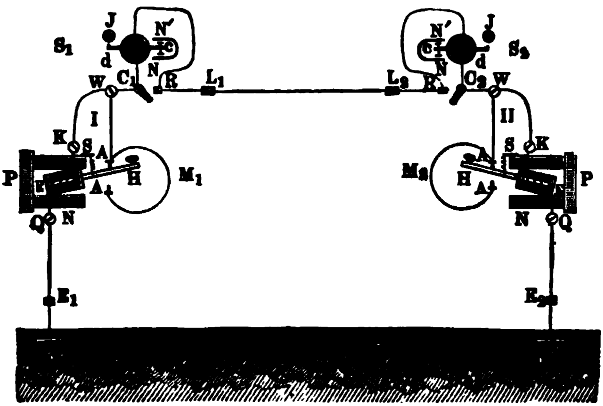


Fig. 314.

and the induced currents which are set up in the coil of the moving armature take the following course at station I. : from the coil at E, through K W C_1 R and L_1, over the line to L_2, thence through R to the electro-magnet E of the ink-writer S_2, and finally to earth by C^2 W A H Q and E_2. The ink-writer S_2 is operated as in the other case.

STÖHRER'S DOUBLE STYLE APPARATUS.

With a view of reducing the number of signals, or more especially, the time occupied in transmitting the signals of the Morse alphabet, Stöhrer invented an apparatus, the register of

which was provided with two electro-magnets, operating separate writing levers, but recording upon the same strip of paper, thus rendering four elementary signals instead of two available for the construction of an alphabet. The two magnets of the register are operated by the current of a single local battery, which

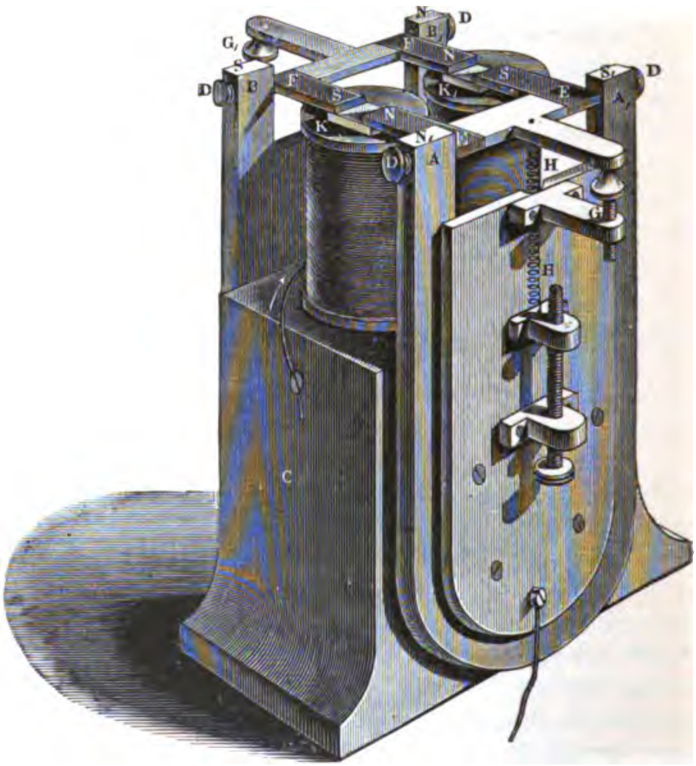
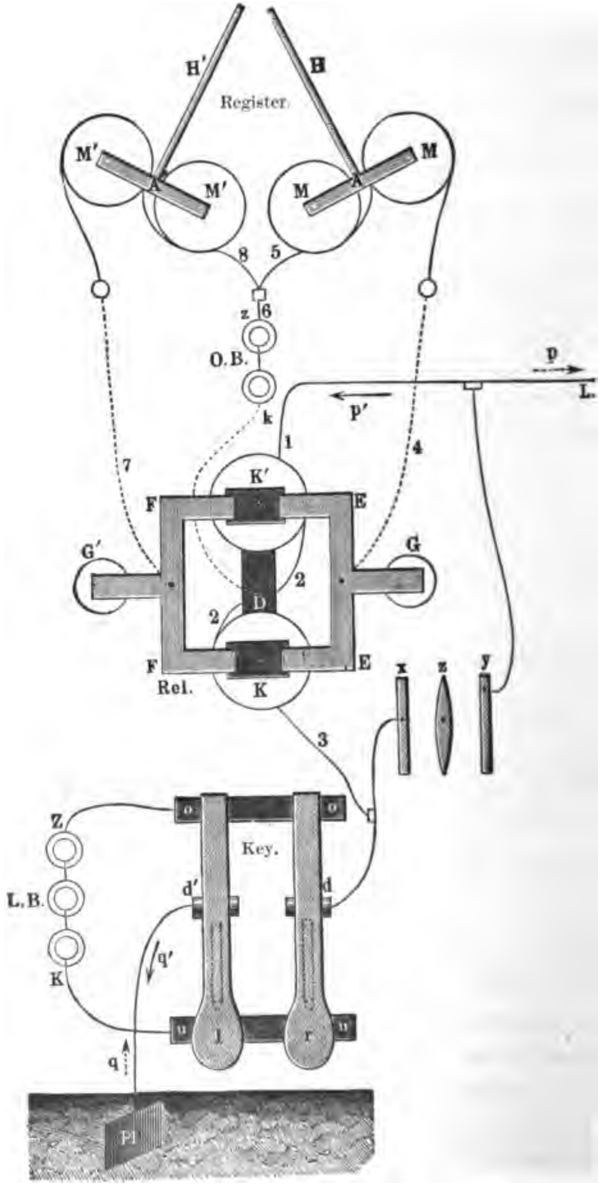


Fig. 315.

is directed through one magnet or the other by means of a double-acting relay, having two polarized or permanently magnetic armatures, which are attracted or repelled according to the direction of the current passing through the relay. A double transmitting key is used, each lever being of the usual construction, with front and back contacts. The relay, as con-

structed by Stöhrer, is illustrated in fig. 315. K K′ are the coils of the electro-magnet. On each side and parallel to it are fixed the permanent steel magnets A A′ and B B′. N and S are the north and south poles of B B′, and N′ and S′ are the north and south poles of A A′. To the former are pivoted two soft iron armatures F N and F S, and to the latter two other armatures N E and N S. Each pair of armatures is yoked together by a non-magnetic piece of brass, and is provided with a projecting arm, which arms strike against the stops G G_1 by the tension of the adjustable retracting springs H. A current of one polarity causes the magnet K K′ to attract one compound armature and repel the other, while a current of the opposite polarity produces the reverse effect. A plan of the whole apparatus is given in fig. 316. The left and right keys are shown at *l* and *r*, the lever of the former being connected to the earth by its axis *d′*, and wire *q′*, and that of the latter to a switch *x y z*. The line wire L passes through the helices K K′ of the relay by the way of 1, 2 and 3, and thence to the axis *d* of lever *r* and to earth. The front and back contacts of the keys *l* and *r* are made of metal bars *u* and *o* common to both, and the line battery L_1 B is connected between those bars, as shown in the figure. The copper pole *k* of the local battery O_1 B is attached to D, and is therefore permanently connected with the poles of the electro-magnet; the other pole *z* goes to the register magnets M and M′, and thence by wires 4 and 7 to the respective armatures E and F of the relay. To transmit to another station the switch *z* is turned so as to form a connection between *x* and *y*. The depression of the right hand key *r* sends a copper or positive current to line, and the left hand key *l* in like manner a zinc or negative current. By opening the switch *x* the apparatus is ready for the reception of despatches. The line currents come in at L and pass throught the relay K K′ by way of 1, 2 and 3, and thence through *d o d′* and *q′* to the earth. When a positive current passes through the relay, F is attracted and E repelled, the local circuit of M′ is closed, and the marking point connected with its lever H′ is brought in contact with

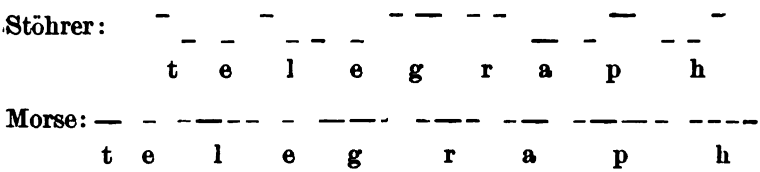


H'
H
Register
M'
M'
A
M
M
A
8
5
z
6
O.B.
p
L.
p'
k
1
4
7
K'
F
E
G'
G
2
D
2
F
E
Rel.
K
x
z
y
3
Z
o
o
Key.
d'
d
L.B.
q'
K
u
l
r
u
q
Pl

Fig. 316.

the paper upon the register. When the sending station depresses the other key a negative current is sent, which in turn repels the armature F and attracts E, thus closing the local circuit through M and actuating the lever H instead of H′. The elementary signs, the dot and dash, in each of the two rows give four elements for the construction of a code, from which it results that fewer signals are required for the formation of the characters than in the regular Morse code.

An idea of the comparative amount of time theoretically gained by this process over the ordinary Morse is seen by comparing the word "telegraph" when written in the Stöhrer and international alphabets respectively.



Taking the dot as a unit of time, and the dash as equal to two dots, while the spaces between the elements of a letter are equal to one dot, and the spaces between the letters themselves are equal to one dash, the transmission of the word "telegraph" by Stöhrer's code will require 44 units of time, whereas by the international code it will require 61.

The double style apparatus has been used to some extent in Bavaria, but it has not been found that its practical superiority over the ordinary arrangement is sufficient to lead to its adoption to any extent. In a modified form, however, the double key and reversed currents of Stöhrer's system exist in the recording apparatus now employed in working submarine cables, and which will be described in a subsequent chapter.

CHAPTER XXXII.

THE NEEDLE TELEGRAPH.

In the account of the early experimental telegraphs, which has been given in Chapter XXIX, it has been stated that a telegraph operating upon the principle of the deflection of a needle or needles by the galvanic current had been invented by Baron Schilling, of Cronstadt, in 1832, which he had exhibited to the Emperor of Russia. From that date experiments with the magnetic needle and multiplier became popular in scientific lecture rooms, and the instrument itself, under the name of the galvanometer, was used as an ordinary experimental instrument for measuring the force of electric currents. Professor Wheatstone showed such experiments with two galvanometers, at King's College, London, certainly as early as 1836. The Professor also records that Baron Schilling exhibited his magnetic needle telegraph at the meeting of German naturalists at Bonn, in 1835. It appears that Professor Müncke, of Heidelberg, was at Bonn on that occasion, and on his return made models of parts of Schilling's apparatus, which he exhibited in his lecture room at Heidelberg. William Fothergill Cooke, a young Indian officer, witnessed in March, 1836, one of Professor Müncke's experiments of this kind, and he was instantly struck with the thought that it formed the basis of a practical electric telegraph. He immediately foresaw the great advantage to society that would result from its general introduction, and he set himself to work to realize this great idea. Within three weeks from that day, he had constructed, partly at Heidelberg and partly at Frankfort, his first electric telegraph of the galvanometer form. He made use of six wires, forming three metallic circuits, and acting upon three needles. By the single and combined movements of these three needles he worked out an

alphabet of twenty-six signals. The needles were suspended so as to move horizontally, each needle being capable of two movements and three positions, namely, at rest, or parallel to the coil, and a right hand and left hand deflection, according to the polarity of the current by which the deflections were caused. But the leading feature of Cooke's invention consisted in the fact that it did not merely send signals from one place to another, which was all that had been accomplished by its predecessors, but even at that early period it was organized into a reciprocal telegraphic system, by means of which a mutual communication could be practically and conveniently carried on between two distant places; the requisite connections and disconnections being effected by pressing the fingers upon keys, and the signals being exhibited to the person sending the communication as well as to the person receiving it. This result was effected by placing a system of keys permanently at each extreme end of the metallic circuit, and providing each circuit with a switch or connector for completing the continuity of the wires, when signals were being received from the opposite terminus. The two signaling instruments being thus both included in the metallic circuit, every signal was exhibited simultaneously at both stations, while the switch or connector (which Mr. Cooke termed a draw-bridge), was made to restore the circuit for a reply upon the completion of the original communication. This united and reciprocal property is of necessity a fundamental principle of the practical electric telegraph. It was Mr. Cooke's leading idea from the commencement of his labors; the distinguishing characteristic of his instruments from first to last, being that the keys and signaling apparatus were in all cases joined together into one instrument, and the several instruments into one reciprocal system.

Before the end of March, 1836, Mr. Cooke invented the electro-mechanical alarm, which was a necessary adjunct to his telegraph. It was of ordinary construction, worked by clockwork mechanism on the removal of a detent. Mr. Cooke's invention consisted in placing a voltaic magnet in such proximity

to an armature of soft iron attached to the tail end of a lever detent, that when the magnet was charged the detent was removed from the clockwork. When the magnet ceased to act the detent was replaced in the clockwork by means of a reacting spring, or balance weight. This was the earliest application of the electro-magnet to the detent of a clock train to control its motion; an important step in practical telegraphy, which, as we shall hereafter see, lay at the foundation of the dial and type printing telegraphs. In February, 1837, while engaged in completing a set of instruments for an intended experimental application of his telegraph to a tunnel on the Liverpool and Manchester Railway, Mr. Cooke became acquainted, through the introduction of Dr. Roget, with Professor Wheatstone, who had also previously paid considerable attention to the subject of transmitting signals by electricity, and had made several discoveries of the highest importance in connection with the subject. Among these were his well known determination of the velocity of electricity; his experiments in which the deflection of magnetic needles, the decomposition of water, etc., were produced through greater lengths of wire than had ever before been experimented upon; and his permutating key board, by which a few wires could be converted into a considerable number of circuits, so that they might produce the greatest number of signals which were capable of being transmitted through a given number of wires by the deflection of magnetic needles. Mr. Cooke was originally led to confer with Professor Wheatstone in consequence of the difficulties which he had encountered in attempting to telegraph through considerable lengths of wire. The conference resulted in the formation of a partnership between the two gentlemen, and their first joint patent was taken out in May, 1837. Shortly afterwards, owing to Mr. Cooke's enthusiasm and energy, the telegraph was brought into practical use, first upon railway and afterwards upon commercial lines. The earliest demonstration of the practicability of the system was made by the establishment of an experimental line between Euston Square and Camden Town, on the London and

Birmingham Railway. The first actual working telegraph was erected in 1838, between Paddington and West Drayton, on the Great Western Railway, and was about thirteen miles in length. This line had six wires and five needles, and was constructed on Wheatstone's plan, by which two converging needles were made to point to letters upon a dial, an entirely different arrangement from that invented by Cooke, which has already been referred to, but which has been confounded with it by many writers upon the subject. The distinction between Wheatstone's method and Cooke's, assuming the reciprocal arrangement of the latter as the basis of both, may be properly described as the difference between duality and unity of action. Each of Wheatstone's simple signals was indicated, as above stated, by the convergence of two separate needles, deflected by a current overcoming the resistance of two sets of coils, and was produced by the depression of two separate keys, being the terminals of two sets of wires, upon the metallic connections of the battery. In Cooke's plan, on the other hand, each signal was indicated by one needle, deflected by a current transmitted through a single set of coils, and was produced by the movement of a single key or handle turning on a horizontal axis, which being the continuation, not of a conducting wire, but of the two poles of the battery, produced the transmission of a current in one direction by a single movement to the left, and in the other by a single movement to the right.

The modern single needle apparatus, of which there are over three thousand employed on the telegraph lines of Great Britain, is a further development and simplification of Cooke's original Heidelberg telegraph of 1836. It has been perfected by the adoption of Prof. Wheatstone's vertical needle and of the metallic battery contacts from his permutating key board, and also by a self-acting drawbridge or circuit-closer. The first public line was opened between London and Gosport in February, 1845. The first matter telegraphed was the Queen's speech at the opening of Parliament, which was received at Gosport by Mr. Cooke himself at the rate of 1,800 letters per hour.

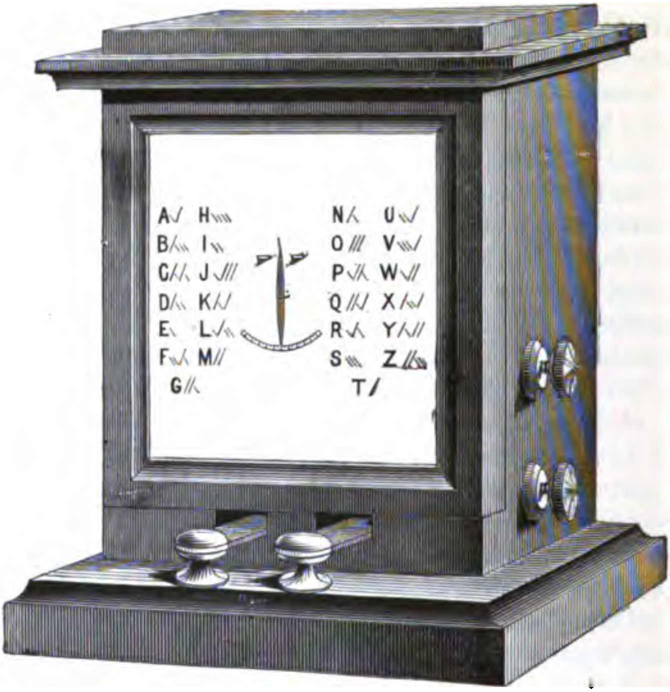


Fig. 317.

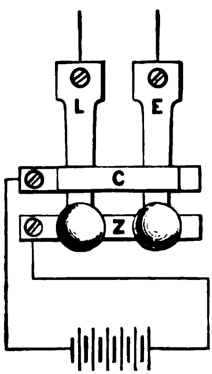


Fig. 318.

Fig. 319.

Fig. 317 represents the exterior of the single needle instrument. In the centre of the face is suspended the index, or pointer, attached to the magnet, which can deflect only a short distance to the right or left of its zero, on account of the stops. The alphabet is formed by movements of the needle or pointer to the right or left. A turn of the top point of the needle to the left indicates a dot, a turn to the right a dash. Thus A is made by a movement to the left and one to the right; H by four movements to the left. Formerly the single needle instrument was operated by the movements of a vertical handle, the right or left movements of which sent currents of different polarities, but this has been superseded by a pair of current reversing keys. The interior of the apparatus consists of two helices of fine silk covered copper wire, in the middle of which is suspended a small magnetic needle, having at the end of its axis the pointer seen on the outside of the instrument. There is also a double key, the two knobs of which protrude through the front of the instrument near the base. The key is represented in fig. 318. L and E are two levers connected respectively with the line and with earth. When they are not depressed, they both rest against the upper bar C, which is connected with the positive pole of the battery. Either lever can be depressed so as to come in contact with the bar Z, which is connected with the negative pole of the battery. If L is depressed a negative current flows into the line, and if E is depressed a positive current flows into the line. The receiving instrument at the other end of the line is so constructed that the depression of the left hand key causes a deflection of the pointer to the left; a depression of the right hand key a deflection to the right. The needle S N, and pointer *a b*, are shown in fig. 319.

The alphabet now used upon the Morse ink-writer and sounder, the single needle, Bright's bell and the cable instruments, contains precisely the same combinations, but differently expressed; thus, upon the Morse ink-writer the letter E is represented by a dot; upon the sounder by a short click; upon

the single needle by a movement of the pointer to the left; upon the bell by a stroke on the left bell; and upon the cable instrument by a spot of light to the left of the zero mark on the scale. The letter T is represented on the Morse recorder by a short line; on the sounder by a longer sound than that required for a dot; on the single needle by a movement of the pointer to the right; on the bell by a stroke on the right bell; and on the cable instrument by a spot of light to the right of the zero mark on the scale.

THE DOUBLE NEEDLE TELEGRAPH.

This apparatus consists simply of two single needle telegraphs, similar in principle to that just described, which are mounted in the same case, their indicating needles being placed side by side upon the same dial, and the handles of their commutators so placed that they may be conveniently operated simultaneously by the right and left hand of the signaler. Each instrument is altogether independent of the other, having separate accessories and transmitting its current upon a separate line wire. It is obvious, therefore, that the use of this apparatus involves twice the expenditure in the construction and maintenance of wires that the single needle does, while it has been found by experience that the increase in the speed of transmission, resulting from the use of the two wires in one instrument, is not proportionately greater. For this reason the use of the double needle instrument, which was formerly quite common upon the more important circuits of Great Britain, has now become exceptional, and will probably before long be entirely discontinued.

The single and double needle instruments have been employed only on the lines of Great Britain and India, and to a limited extent in France. On all the more important lines they have been gradually superseded by the Morse apparatus.

APPARATUS FOR WORKING SUBMARINE CABLES.

The peculiar conditions which are met with in the transmission of electricity through long submarine lines, and which have been

set forth in detail in Chapter XXVII, render it necessary to employ apparatus and methods for telegraphic correspondence which differ very materially from those used for land lines. The general principle, however, is that of the single needle telegraph of Cooke. In order to avoid any possibility of injury to the insulating coating of the cable, it is an essential condition that none but very weak currents should be employed, and for this reason the ordinary receiving instruments, which for the most part depend upon the action of electro-magnets and require currents of considerable force to actuate them, are not available. It would occupy too much space to refer in detail to all the reasons which render it necessary to employ on long cables, like those which have been laid across the Atlantic Ocean between Europe and America, the sensitive reflecting galvanometer of Thomson, which has already been fully described in its various forms in Chapter XV. It therefore only remains to describe the arrangement of the apparatus at the stations by which the effects of the phenomena of induction are overcome and the speed of signaling increased to the greatest practicable extent.

In fig. 320 the manner in which the different parts of the apparatus are arranged at Valentia and Newfoundland for operating the Atlantic cables is shown in the form of a diagram. The condenser C is constructed upon the plan described in Chapter IV and illustrated in fig. 21. It consists of alternate sheets of tin foil and paraffined paper, interleaved, and contains an aggregate inductive surface of 40,000 square feet. It occupies a space three feet long, two feet wide and five inches thick, and is inclosed in a box and surrounded on all sides by a thick body of paraffin. The switch *e r t*, is a common three point switch, which serves to connect the cable K either with the transmitting keys T or the reflecting galvanometer G (which forms the receiving instrument) when sending or receiving. The double key T, in connection with the battery B, is arranged in the same manner as the one shown in fig. 318, so that one key *a* sends a positive and the other *b* a negative current from the

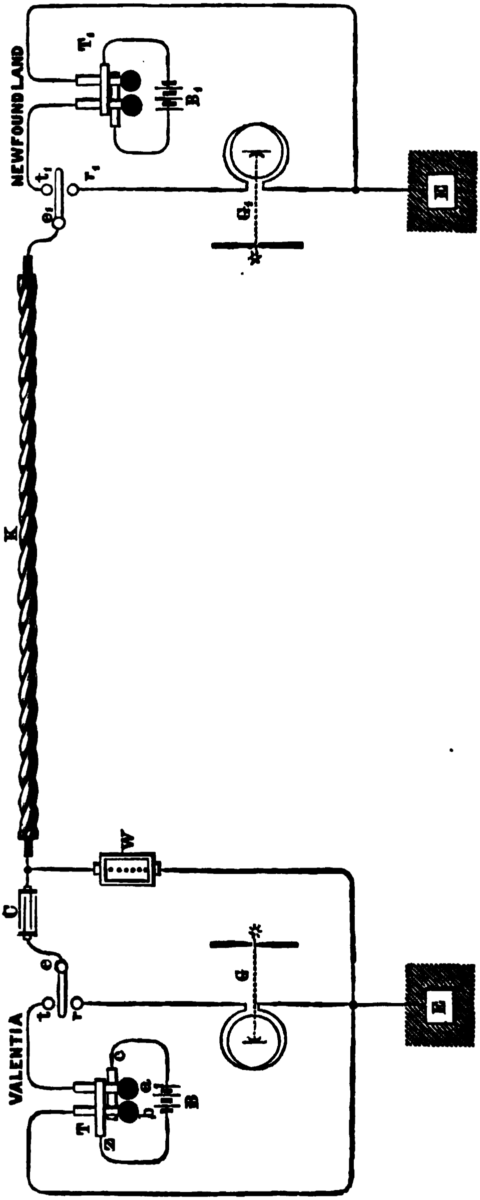


Fig. 320.

battery to line. W is a very large resistance, which connects the end of the cable K to the earth, at the point where the former is attached to one side of the condenser C. The battery B usually consists of about five elements of the kind illustrated in fig. 38.

If Valentia wishes to transmit to Newfoundland the operator shifts the connection of the switch at *e* from *r* to *t*. When the key *a* or *b* is depressed, then one set of plates of the condenser C is charged either with positive or negative electricity, as the case may be, in the manner explained in Chapter IV. If, for example, the key *a* is depressed, then the + E of the battery flows by way of *c a t* and *e* to one set of plates of the condenser; hence the — E of the cable, in connection with the earth at Newfoundland, is attracted, and condensed on the other set of plates, which are connected with the cable, while the + E of the cable is at the same time repelled and driven towards Newfoundland. In this way there arises in the cable a positive current from Valentia towards Newfoundland, passing at the latter station by the way of *e′* and *r′* to the receiving instrument or galvanometer G′, and thence to the earth, and by the deflection of the spot of light upon the scale produces a + indication. When the key *a* remains depressed but for a moment the flow of current through the cable is of short duration, for as soon as the key is released and touches the bar *z*, not only does the process of charging the condenser terminate, but its discharge as well as that of the cable itself immediately commences. The + E of one side of the condenser immediately begins to flow to earth by way of *e t a z* and *b*. This sets free the — E of the opposite side of the condenser, which flows off through the cable to Newfoundland. On the other hand, the + E still present in the cable, not having had time to escape to the earth at Newfoundland through the galvanometer G′, flows in the direction of Valentia, where the cable is in connection with the earth through the very large resistance W. Therefore there will be, under these circumstances, two simultaneous currents in the cable of about equal strength, but of opposite polarity or

direction, which reciprocally neutralize each other, and thus destroy the inductive action which the original positive current had set up in the outer coating of the cable. By this means the cable becomes completely discharged.

By making use of a similarly arranged condenser in Newfoundland, a communication may, in the same manner, be forwarded in the opposite direction; though it is stated that the Atlantic Telegraph Company, in order to avoid Varley's patent, have not adopted the system devised by him, but operate the cable by the use of a single condenser C at Valentia, which answers for transmission in both directions. With a single condenser the signals are sent from Newfoundland in the following manner:

When a key is depressed at T′, then the electricity, for example the + E, flows directly into the cable K, and arriving at Valentia flows almost entirely into the side of the condenser C, which is attached to the cable, the resistance of W being so great that comparatively little of it goes to the earth. The accumulation of + E in one side of the condenser causes a like quantity of + E to be driven out of the opposite side of the condenser, passing through *e r* and G to the earth, giving a + signal upon the galvanometer. When the depressed key at Newfoundland is again released, putting the cable at that place to earth, then the + E stored up in the condenser flows back into the cable, producing a + current towards Newfoundland, which lasts for a certain time, partly because the discharge of the condenser is not instantaneous, and partly on account of the inductive action set up by the original current. At the same time the — E from the opposite side of the condenser flows through the galvanometer G to the earth, and produces a — signal. In consequence, however, of the great distance between the condenser and the battery, and the short time during which the keys are depressed in transmitting signals, the potential of the charge of the condenser is only about one per cent. of that of the battery itself. For this reason the — E which flows from the opposite side of the condenser through the galvanometer to the earth produces a very weak pulsation, which has

but little effect upon the needle other than to make it return more quickly to its position of rest, and does not in any way interfere with the regular signals.

It will be seen, therefore, that in this method of working the cable by means of a single condenser, the depression of the positive key at either terminal station produces exactly the same result, namely, the deflection of the needle towards the + side, and in like manner the depression of the negative key at either station gives a — signal. The combination of these two signs, so as to form letters and words, according to the Morse code, is precisely the same as in the single needle instruments, which the cable instruments in fact are.

The insertion of the shunt W, having a very high resistance, which may be considered almost infinitely large in comparison with that of the conductor of the cable, gives rise to only a small loss of current, while it keeps the cable in constant connection with the earth—a result in many respects advantageous. The advantages gained by working with condensers instead of a direct current from the battery, may be briefly stated as follows: The direct current can only affect the galvanometer by first charging the entire cable, while the flow of electricity from the condenser through the galvanometer to the earth commences at the same instant as the charging. When, therefore, the key is depressed, the indication upon the galvanometer follows much more quickly with the condenser than it would with a direct battery current. In addition to this, the period of deflection only lasts during the time of charging, for the moment the potential of the condenser equals that of the pole of the charging battery, the needle immediately returns to zero, even if the key remains depressed. The practical advantage of the method of working with condensers is so great, that a speed of from twelve to eighteen words per minute is reached on the cables between Valentia and Newfoundland.

The reflecting galvanometer, and its application as a receiving instrument, has already been spoken of at some length on page 156. For long cables the astatic form of Thomson's reflecting

galvanometer, shown in fig. 321, and which has been fully described and illustrated in Chapter XV, is frequently employed. Fig. 322 is a sectional view of the coils, about half the actual size, showing the mirror M and the lower needle N, but which requires no detailed description in this place. When these instruments are used for receiving communications through the cable they are placed in a box or curtained compartment, and

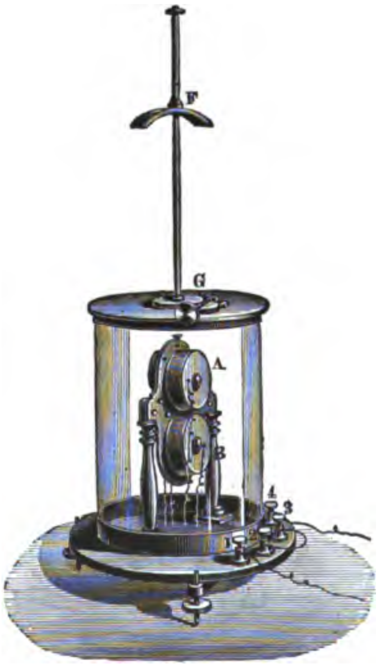


Fig. 321.

Fig. 322.

the receiver calls off each word to a clerk in attendance, who writes it down. The spot of light wanders over the scale, following every change of current, but the operators, by practice, acquire the necessary skill to interpret the apparently irregular motions. One dot will cause the light to almost cross the scale, the second moves it a little further, the third or fourth cause hardly a perceptible motion, but the receiver knows by ex-

perience that these four very different effects each indicate a single dot, all of them being sent by the transmitting operator in precisely the same manner.

THOMSON'S SYPHON RECORDER.

This beautiful apparatus was invented by Sir William Thomson, who has contributed, perhaps, more than any other person to render submarine telegraphy commercially practicable. The syphon recorder is so arranged as to actually delineate on paper the apparently irregular movements of the galvanometer needle

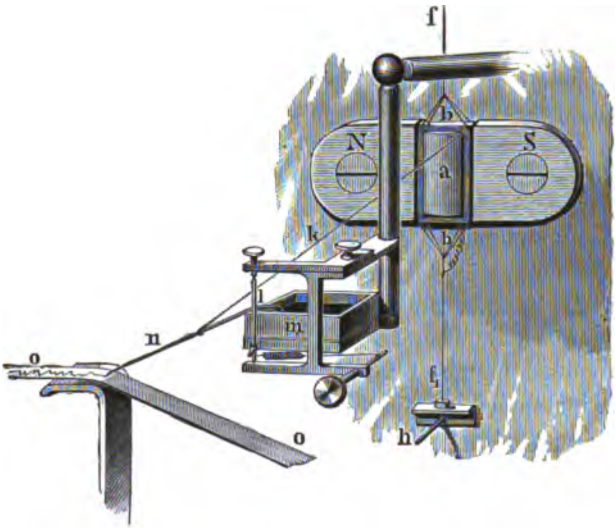
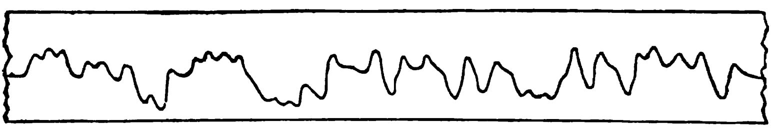


Fig. 323.

above referred to. A fine glass syphon tube conducts the ink from a reservoir to a strip of paper, which is drawn past the point of the tube with a uniform motion. The point moves to the right or left of the zero line through distances proportional at each instant to the strength of the current, and thus the signals are drawn on the paper in the form of curves, representing the strength of the current at each instant of time. Fig. 323 shows the form of syphon recorder in use at the Duxbury

station of the French Atlantic cable. The apparatus consists of a very light rectangular coil *b b* of exceedingly fine insulated wire, suspended between the poles of a large and powerful electro-magnet N S, which is charged by a local battery of large size. Within the coil is a stationary soft iron core *a*, which is powerfully magnetized by induction from the poles N S. The coil *b b* swings upon a vertical axis, consisting of a fine wire $f f_1$, the tension of which is adjustable at *h*. The received current passes through the suspended coil, the suspension wire $f f_1$ serving as the conductor; the coil is impelled across the magnetic field in one direction or the other, according to the polarity and strength of the current passing through it. The magnetic field in this arrangement is very intense and very uniform, which makes the apparatus sensitive to the weakest currents. The syphon *n* consists of a fine glass tube turning upon a vertical axis *l*; the shorter end is immersed in the ink reservoir *m* and the longer end rests upon the paper strip *o o*. The syphon *n* is pulled backward and forward, in one direction by the thread *k*, which is attached to the swinging coil *b b*, and in the other by means of a retracting spring attached to an arm on the axis *l* and controlled by the adjusting spindle *g*. The paper is caused to move at a uniform rate by means of gearing driven by a small electro-motor. Fig. 324 is a fac-simile of the



S I P H O N R E C O R D E R

Fig. 324.

writing of the syphon recorder at a speed of eighteen or twenty words per minute through a cable of about 800 miles in length. The upward waves represent dots and the downward waves dashes, and by bearing this in mind the words "siphon recorder," written in the International alphabet given on page 480, may be readily traced out. In working very long cables

the action of the current upon the swinging coil is very feeble, and the friction of the syphon against the paper strip, if allowed to come in actual contact with it, would interfere with the freedom of its movements. In such cases the point of the syphon does not actually touch the paper; the ink and the paper are oppositely electrified by means of an inductive machine driven by the same electro-motor which moves the paper. The electrical attraction causes the ink to be ejected from the syphon upon the paper in a succession of fine dots. Fig. 324*a* is an example

Fig. 324*a.*

of the record made in working through a long cable. The apparatus at Duxbury, shown in fig. 323, has been materially modified from the original plan, and its working much simplified and improved, by Mr. Cuttriss, the mechanician at that station.

It is somewhat curious that, in the progress of telegraphic improvement, Morse's telegraph, the most valuable feature of which originally was considered to be its capacity for recording communications, should have been modified in practice into an acoustic semaphore, while Cooke's telegraph, originally a semaphore, should at length have been also modified into a recording instrument, in the form which we have just described.

CHAPTER XXXIII.

THE DIAL TELEGRAPH.

ANOTHER very large class of telegraphic instruments is included under the general designation of dial telegraphs. In these instruments a pointer or index hand is caused to revolve, by means of suitable mechanism, over a series of letters, numerals or other characters, placed around the circumference of a dial behind or underneath it, and arrangements are provided by means of which the pointer can be stopped in front of any particular character, and may thus be made to spell out the desired communication letter by letter, at the will of the sending operator.

Although the mechanism which is required to move an index or pointer in this manner is necessarily much more complicated than that which suffices to produce the simple deflection of a needle, to say nothing of the fact that certain special devices are also necessary for the purpose of securing a synchronous movement of the mechanism of the two instruments in correspondence, yet a dial apparatus which is rapid and reliable in its action is for many purposes considered preferable either to the Morse or the needle instruments. For this reason a great number of dial instruments have been invented, which have been employed to a greater or less extent in different countries.

WHEATSTONE'S FIRST APPARATUS.

The first application of the attraction of an electro-magnet to a clock train, to control its motion or to ring a bell, was made by Mr. William F. Cooke, the idea having suggested itself to him in March, 1836, shortly after the invention of the three needle telegraph described in the preceding chapter. Mr. Cooke reasoned that if the function of the electric current could be

confined merely to the office of causing suitable interruptions or divisions in any kind of motion derived from an independent source, that the diversity of the signals could be made to depend entirely upon the mechanism. He proposed to accomplish this result by the use of an electro-magnet, the armature of which was attached to a detent acting upon a revolving cylinder similar to that of a common musical box, driven at a uniform rate of speed by clockwork. A series of pins were arranged spirally upon this cylinder, so as to be each struck by the corresponding one of an equal number of keys. The operation was as follows: When any particular key was depressed at the sending station the circuit of the line was closed, releasing the clockwork of each instrument through the agency of its electro-magnet. Both cylinders and dials then revolved in unison until the depressed key at the sending station was struck by its corresponding pin, which interrupted the circuit again, and stopped both instruments at the same point, thus indicating the desired letter or character. It was Mr. Cooke's inability to make the electro-magnet act at long distances which first led him to consult Professor Wheatstone in February, 1837. It was not however until 1839, after Professor Wheatstone had succeeded in perfecting the electro-magnet by the employment of a long and thin wire of many convolutions in forming the helices, instead of the short and thick wire originally used, that any further advance was made in the construction of this class of instruments. In the autumn of that year Wheatstone invented his first dial telegraph. This apparatus appears to have undergone several modifications within a year or so. The principle of its action, however, remained the same in each case; it was that of sending from the transmitting station a series of alternate currents through the line, which, passing around the soft iron cores of an electro-magnet, moved an armature and controlled the motion of a step-by-step escapement, similar to that of a clock.

The transmitting portion of Wheatstone's original apparatus consisted of a commutator so arranged as to direct the current

of a battery alternately through two separate electro-magnets at the receiving station. It is represented in fig. 325. The direction of the current is controlled by means of a toothed wheel K, supported upon a metal standard S S. The teeth of this wheel, to the number of fifteen, are so arranged that the teeth and spaces in consecutive order represent thirty letters of the alphabet, numerals, etc. Upon each side of the wheel are placed contact springs n n', so arranged that only one of them

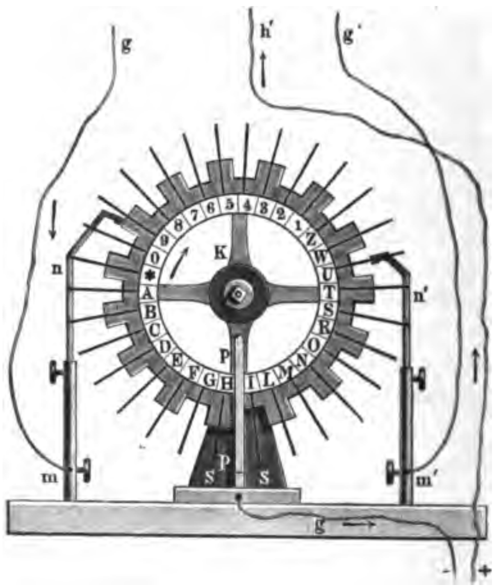


Fig. 325.

is in contact with the wheel at the same time; when one presses against a tooth the other one is always opposite a space. These springs are connected to the respective line wires g and g', and a battery is connnected to the common return wire g attached to the standard S S. From the circumference of the wheel K project thirty arms, after the manner of a capstan, and upon the base of the standard is a bar P, used as a stop for the hand of the operator when turning the capstan wheel K of the trans-

mitter, for the purpose of signaling the letter opposite the arm taken hold of by him.

The receiving instrument or indicator is shown in fig. 326. It consists of a dial having thirty divisions corresponding to the various letters and characters of the transmitter. The index hand *z*, which moves over the dial, is driven by a system of

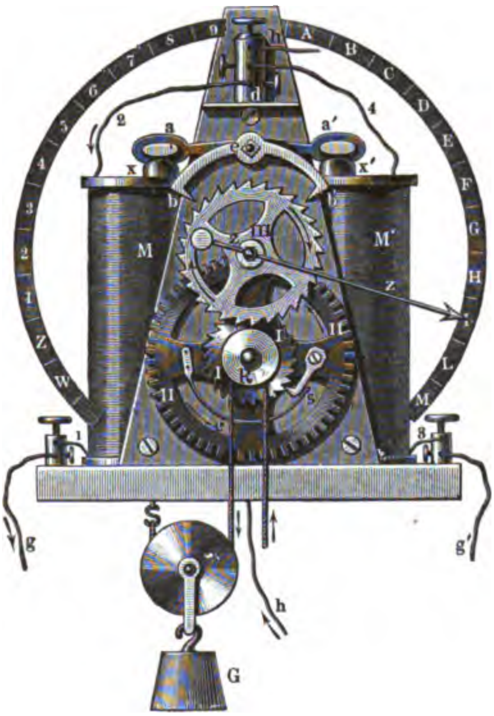


Fig. 326.

clockwork, put in motion by the weight G. The clockwork is controlled by an escapement *b b'* fixed in the axis *e* of a beam supporting two armatures *a a'* of soft iron over the poles of two electro-magnets M M', included in the circuits of the respective line wires *g g'*. As the toothed wheel K of the transmitter is turned round, alternate currents are sent through the contact

springs n n', through the lines, and through the magnets M M′. Therefore, whenever the toothed wheel of the transmitter is stopped at any point, a current from the battery circulates in one or the other of the magnets M M′, the armature of the magnet is held down, and the index prevented from moving farther around the dial.

Very soon after the invention of this apparatus, Wheatstone made an important improvement in it, by dispensing with one of the line wires, as well as its corresponding contact spring and electro-magnet. This was an important step in the right direction, and fulfilled one of the most essential conditions of a successful telegraph, that of requiring but a single line wire. In Wheatstone's improved indicator the functions of the second electro-magnet were performed by a retracting spring, provided with an adjusting device for tightening or loosening it. This spring acted in opposition to the single electro-magnet, and, of course, with inferior force. It had sufficient tension, however, to separate the armature from the poles of the electro-magnet, and operate the escapement whenever the current circulating in the helices of the electro-magnet was interrupted.

A patent embracing these and other improvements in dial telegraphs was taken out, in 1840, by Messrs. Wheatstone and Cooke. Among the most important of these modifications was the substitution of currents derived from a magneto-electric machine for battery currents; an application which, in later years, has been brought to great perfection.

Wheatstone's dial instrument was introduced on the railway lines of North Germany, to some extent, prior to 1848, by Fardeley, of Mannheim, but afterwards gave place to the improved apparatus of Siemens, which will be hereafter described, and to the Morse system, which was capable of being worked over much longer distances.

BREGUET'S APPARATUS.

The original apparatus of Wheatstone was taken up in France by Breguet, who introduced many improvements both in the

principle and in the details of the mechanism. These improved instruments have been extensively used on the French railway telegraph lines for many years, and have in all cases given good satisfaction.

The transmitting mechanism of Breguet's instrument is shown in fig. 327. It consists of a clockwork arrangement, which is attached by three metallic pillars to a wooden base. The dial is divided into twenty-six divisions, marked with the letters and numerals, and each is opposite a corresponding notch in the cir-

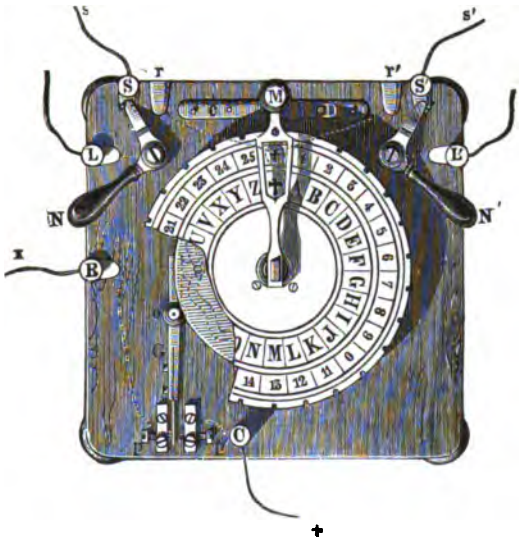


Fig. 327.

cumference of the dial. Beneath the latter is a horizontal wheel provided with a sinuous groove cut in its periphery, and in this there are the same number of curves that there are notches in the dial. The axis of the wheel projects above the surface of the dial, and is provided with a crank M, by which it may be turned. The metallic lever G has its centre of motion at *o;* at one end it is provided with a metallic roller, which runs in the sinuous groove of the wheel just mentioned, by which means it is moved to the right and left as the wheel revolves. The

front end of the lever is provided with a small flat spring, which plays between the adjustable contact screws p and p'. For every revolution of the lower wheel the lever G makes contact with each of the screws p and p' thirteen times. It is also so arranged that the spring rests on the point p when the crank stands on the cross or over an even number, and on the screw p' when it stands over an odd number. A catch projecting from the under side of the crank engages in the notches around the dial, so as to prevent its accidental displacement. Binding posts, for making connections, and two commutators or switches, with handles, N N′, are placed upon the base of the apparatus. The binding post C is connected to the positive pole of the battery and to the screw p', the negative pole of the battery being put to earth. The binding post R is in connection with the screw p, and by the wire x with the receiving instrument of the same station. The post L connects with the commutator N; it also receives one end of the line wire while L′ receives the other, and is connected to the commutator N′. By turning the handles N and N′ the call-bell of the station, which is permanently connected to the binding posts S and S′, may be placed in the main circuit. The metallic plates r r' connect with one of the metallic columns which support the signal dial, and consequently with the crank G.

A metallic strip, c D′, fastened to the base in such a position that the commutators can be turned on to it, permits the operator to cut the instrument out of circuit at pleasure.

When the contact spring of the lever G presses against the screw p, the two metallic pieces r r' being permanently connected with it through the dial plate, necessarily communicate also with the binding post R, and consequently with the receiving instrument of the station.

Now, if we place the spring of the commutator N on the metallic piece r, and turn the crank M, the lever moves to and fro, and its spring makes contact with the screw p every time that M passes an even number of the signal dial, and with p' when it passes over an odd number. Each time that the lever

makes contact with the screw *p′*, the battery current passes into it, thence through the metallic part of the signal disk to *r*, and through the commutator spring N to the binding screw L and into the line. When, however, it makes contact with the set screw *p*, the line current is interrupted. It consequently follows that for each revolution of the crank M the current is established and broken twenty-six times in all.

The receiving apparatus (fig. 328) consists of a signal dial arranged like that of the manipulator, and a clockwork placed behind it, the escapement of which is regulated by an electro-magnet. Fig. 329 represents the interior of the receiving in-

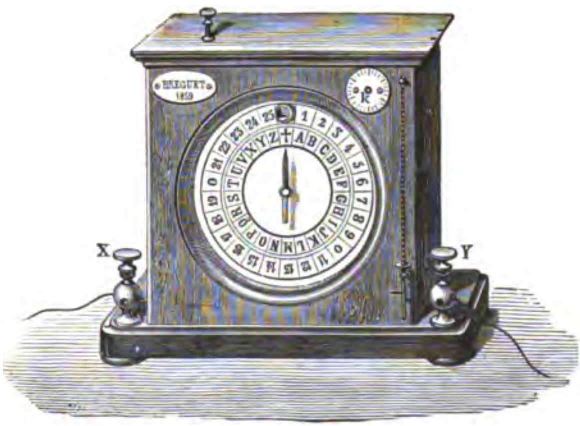


Fig. 328.

strument as seen from the back, with the electro-magnet removed, while fig. 330 shows the arrangement of the electro-magnet and its connections. In the last two figures the same parts are indicated by similar reference letters. M M is a horizontal electro-magnet, whose armature P, suspended between screw points *v v*, has attached to it an arm *q*, projecting upward, and which is limited in its vibration to and fro by adjustable screw stops inserted in the frame *f*. A pin *g* is inserted in the arm *q*, near its upper end, and at right angles to it; this pin works in a fork F, fixed upon the horizontal axis *a*. At the

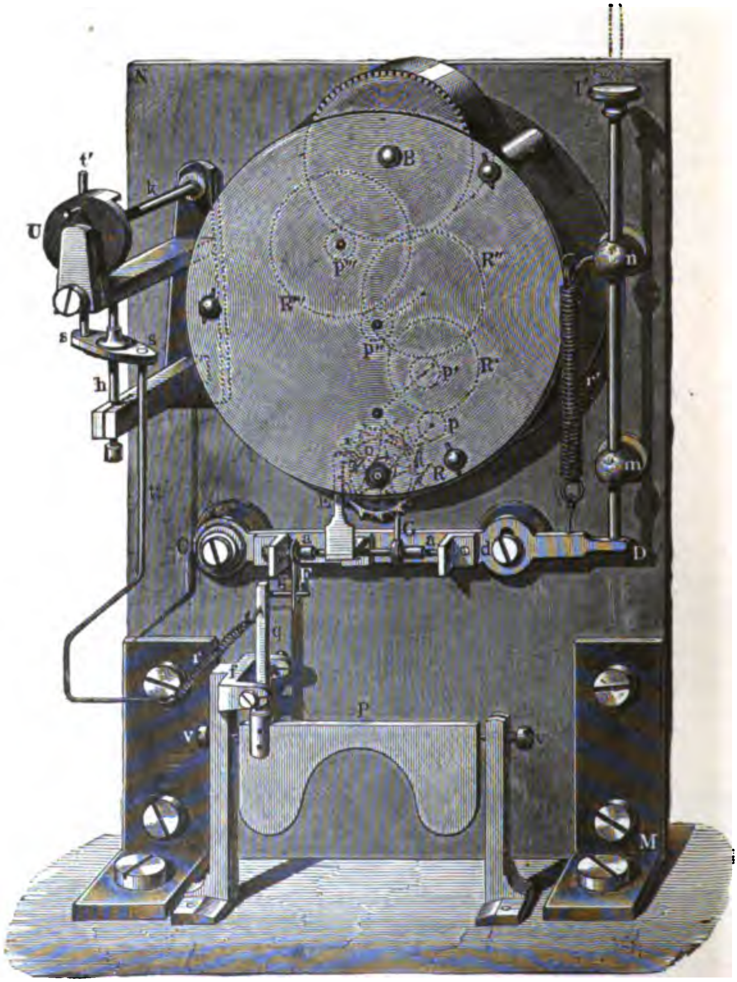


Fig. 329.

opposite end of the axis a a pallet G engages alternately with two parallel escape-wheels R, impelled by the coiled main spring B and clockwork in the case above. The two escape wheels are so arranged upon their common axis that the thirteen teeth of the front and back wheels alternate when viewed from the front. When the apparatus is at rest and the armature held back from the poles of the magnet by the spring r, the pallet locks the teeth of the back wheel; but when the armature is attracted the pallet springs into the teeth of the front wheel,

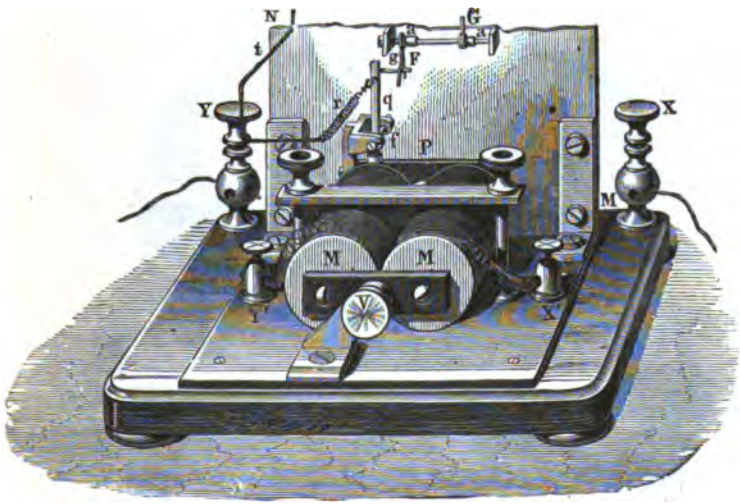


Fig. 330.

which being the distance of half a tooth behind the other as it revolves, allows the wheels and pointer to turn through one twenty-sixth of the whole circle. As soon as the armature is released again the pallet leaves the teeth of the front wheel and re-enters between those of the other. Thus every time the circuit through the magnet M M is either closed or broken the pointer advances one division upon the dial by the action of the clockwork. The retracting armature-spring r is adjusted by means of the bent lever t, upon the end of which it is hooked. The lever itself is fixed to the under side of a bar s, turning

upon a vertical axis h. On the upper side of the bar s, at the opposite end, is a long vertical pin t', which may be gradually turned with the bar through a small angle by means of an inclined plane on the rim of the drum U. The drum is fixed upon a shaft k, which extends outside the case, as seen in fig. 328, and may be turned by means of a key which hangs by a chain to the instrument.

The shaft a, with its pallet and fork, is supported by a movable bar C D, turning upon the fulcrum C at the left, while on

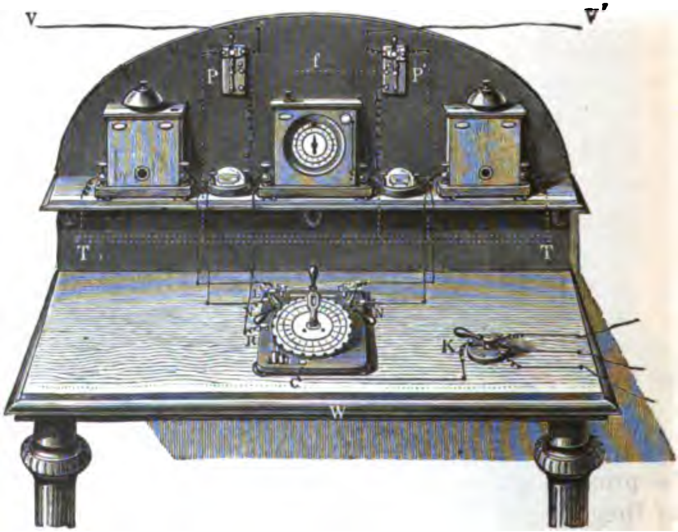


Fig. 331

the right it is held up by a spiral spring r', which forces it against the lower end of a vertical rod passing through the guides m and n. By pressing upon the button I′ of the vertical rod, the bar C D is moved downward and disengages the pallet G from the escape wheels, but at the same time carries the detent E into the path of the pin o, which prevents the clockwork from running down when released from the control of the pallet. The position of the pin o is such that when it comes in contact with the detent E the pointer will be at the zero or +

of the dial. By this arrangement the receiving operator can bring his instrument to zero in a moment, if necessary.

The arrangement of the apparatus at a station is shown in fig. 331. When the line is not in use by any station the switches N and N′ are placed on S and S¹ (best seen in fig. 327); a call signal arriving from either side will be received upon one or the other of the alarms or call-bells. For example, a current arriving from the left by the line wire V goes through the lightning arrester P (which will be hereafter described) and the galvanometer, through L N and S to the earth connection T T. The connections of the other side are similar.

When a call is received from V the operator turns his switch N to *r*, which puts his receiving instrument in circuit. K is a switch by which the number of cells of main battery employed in transmission may be regulated to suit the length of line to be worked through.

Breguet has also constructed a portable apparatus for railway use, upon the same principle as that which has just been described, but so compactly arranged that it is contained, together with its battery, in a moderate sized oaken case, which may be carried from place to place without difficulty.

FROMENT'S APPARATUS.

The principal difference between Froment's telegraph and that of Breguet consists in the construction of the manipulator or transmitting apparatus. The receiving instrument is similar to that of Breguet, and need not therefore be described.

The transmitter of Froment's telegraph (fig. 332) consists of a keyboard like that of a piano, having twenty-six keys arranged in two series, one above the other. The upper or back row contains the cross or terminal signal + and the first twelve characters of the alphabet, and the front row the remaining thirteen.

In the circumference of the escape wheel A, forming part of the clockwork beneath the keyboard, a sinuous groove is formed exactly like that in the Breguet transmitter, in which a roller upon the end of the lever B is made to play. When the wheel

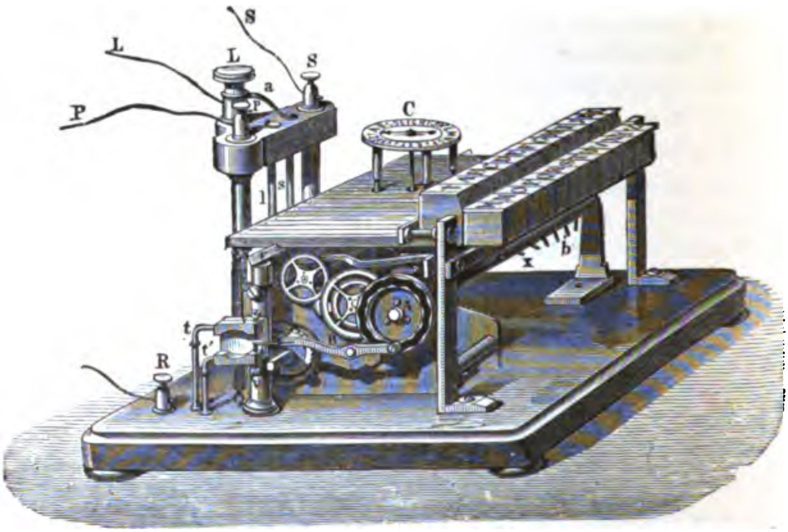


Fig. 332.

A revolves, the opposite end of the lever, consisting of a metallic spring, is caused to move to and fro between the screws *v* and *v'*, thus regulating the interruptions of the current.

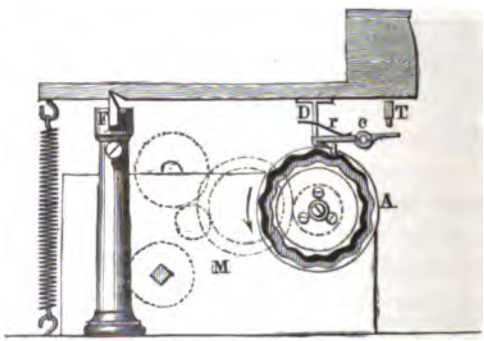


Fig. 333.

The escape wheel A carries a tooth *d* (fig. 333), which is held by the hook *c*; the latter is kept in place by a spring *r*. As long as the tooth is retained the clockwork is arrested, but the moment the hook is raised the tooth becomes free and the

clockwork, being no longer checked, causes the wheel A to turn and thus the free end of the lever B (fig. 332) is made to oscillate. The former figure also shows the manner in which the keys turn on the fulcrum F when they are depressed.

Immediately beneath the keys and along the entire keyboard a wooden bar T T (fig. 334) is placed, by means of which the

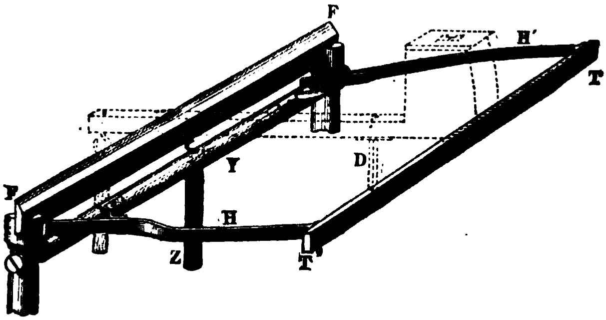


Fig. 334.

operator is enabled to release the escape wheel. This bar is attached by two metallic pieces H H' to a metallic cylinder Y, just below the bar F F, and turns on its own axis. A powerful spring Z keeps this cylinder, and consequently the wooden bar also, in a position of rest so long as no other force acts upon them.

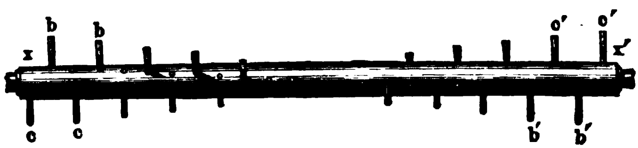


Fig. 335.

When a key is depressed it lowers the wooden bar T T, and thereby sets the wheelwork in motion by releasing the tooth *d*.

It is obvious that the number of interruptions of the current depends upon the number of oscillations made by the lever, in other words, upon the size of the wheel A. In order to use this apparatus for telegraphic correspondence it is only necessary to

add a contrivance by means of which the size of the wheel, or the number of interruptions, can be made to depend upon the position of the depressed key, that is, upon the character which is to be signaled. Froment has done this in the following simple and effective manner:

Attached to the wheel A is a metallic cylinder $x\ x'$ (fig. 335) of the same length as the keyboard, in which two rows of metallic pins are inserted perpendicular to its length. The pins in the first row $b\ b\ b'\ b'$ correspond to the upper keys, and those in the other row $c\ c\ c'\ c'$ to the lower keys. In the figure the cylinder is represented with only twenty-five pins, for the reason that the tooth d supplies the place of the one corresponding to the cross or first key.

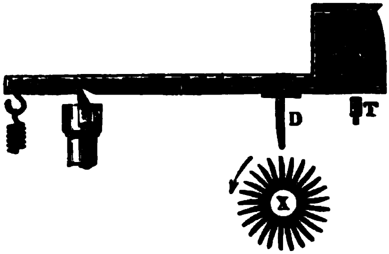


Fig. 336.

Each pin stands vertically out from the cylinder $x\ x'$ in such a position that if a line were drawn through any oneof them and the axis of the cylinder it would form, with a line passing through the next following pin and the cylinder, an angle equal to the 26th part of the circumference of the cylinder.

It follows from this that the thirteen pins of the row $b\ b\ b'\ b'$ (which includes the tooth d), form half of a spiral line around the cylinder; that the thirteen pins of the row $c\ c\ c'\ c'$ form the other half, and that the two halves reciprocally supply each other's places.

A metallic pin D (fig. 336), attached to the under side of each key when the latter is depressed, engages the corresponding pin on the revolving cylinder and thereby arrests its motion.

With this explanation the working of the entire apparatus (fig. 332) will be readily understood.

The terminal post L, which is fixed on a triangular wooden base, receives the line wire L, and is provided with a metallic spring *a*, by means of which it may be placed in contact with one of the two buttons forming the terminals of the metallic columns *l s* at pleasure. Column *s* is in connection with the binding screw S and also with the call bell of the station; column *l* communicates with the metallic part of the clockwork and through this with the lever B. The binding post P receives the wire from the + pole of the main battery, which it places in communication with the contact *v* through the small pillar *t*, and finally the contact pin *v′* is connected to R and also to the receiving instrument of the station by means of the wire *t′*.

When the tooth of the escape wheel is caught by the hook *c* (fig. 333), the spring at the end of the lever B presses against the contact *v′* and the current from the battery of the station is interrupted; the receiving instrument of the station, however, is in a position to respond to the current from the distant station. The groove in the wheel A is so constructed that for each revolution the tongue of lever B is made to strike thirteen times against each of the contact screws *v* and *v′*.

When the instrument is not in operation the spring *a* is connected to the column *s* and call bell. If the operator desires to send a message he first places this spring on the button in connection with column *l*, and then depresses the key marked with a cross. The escape wheel A is thus freed and makes a complete revolution. A similar proceeding on the part of the receiving operator moves the pointer of the first station once around the dial, and so notifies of his readiness to receive. Every time that a key is depressed the escapement wheel becomes free and the lever B oscillates; the line, consequently, receives a series of currents separated by interruptions of like duration, this continues until a corresponding pin in the cylinder *x x′* strikes that of the depressed key. These currents, the number of which depends upon the position of the depressed

key, reach the distant station and there bring the index of the receiving instrument to the character corresponding to that of the key. When the finger passes from one key to another the cylinder x x' and wheel A turn through an angle equal to the one between the pins corresponding to these keys, consequently the number of currents sent into the line is equal to the number of keys or characters between the two keys depressed. We thus see that the pointer at the receiving station must always be in accord with the depressed key at the transmitting station.

Another pointer C, fig. 332, is moved around a dial plate by the clockwork of the sending apparatus, and indicates the characters corresponding to the depressed keys. By means of this the operator is provided with a check to his fingering which enables him to proceed with confidence.

It will be seen that the possible speed of transmission by this apparatus depends upon the velocity with which the cylinder x x' revolves. Breguet's method of interrupting the current presents one disadvantage, in that it burdens the crank axle with an interrupting wheel, whose weight retards the velocity of the crank. This is avoided in Froment's apparatus by the use of a less bulky interrupter, consequently it is capable of being worked at a greater speed. The most important feature in the latter, however, consists in the fact that with it the interruption of the current is taken out of the hands of the operator; it is, therefore, not only less fatiguing to work, but is also capable of higher speed on account of the mechanical arrangement by which the velocity of the escapement wheel can be kept within the proper limits.

CHESTER'S APPARATUS.

An instrument very similar in principle to that of Breguet, but somewhat different in the details of its construction, designed by Mr. Chester, of New York, has been used quite extensively in the United States for municipal or police telegraphs and for private lines. The leading peculiarity of Chester's instrument is, that a single clockwork and a single dial answers for both

the transmitting and receiving apparatus, which are thus combined in one instrument. The circuit-closer is similar to that of Breguet. The transmitter consists of a horizontal arm revolving beneath the dial, which is stopped by the depression of any one of a series of vertical pins corresponding to the different letters, which are arranged around the circumference of the dial. This is a very compact and simple instrument, and answers an excellent purpose for the class of work for which it was particularly designed.

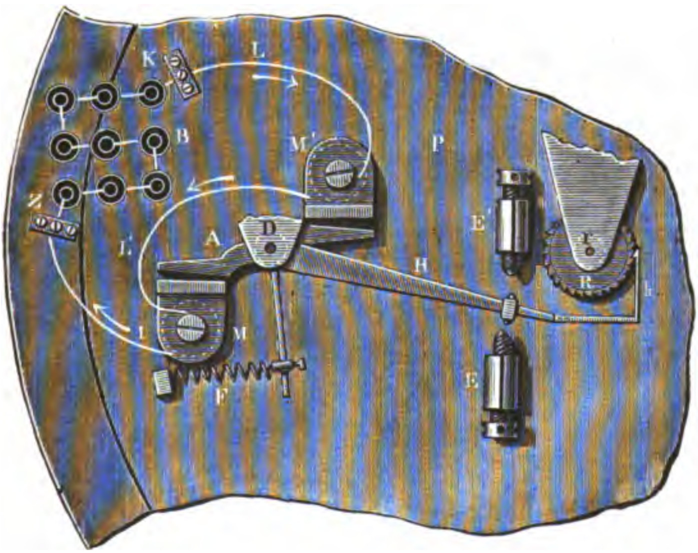


Fig. 337.

SIEMENS'S APPARATUS.

The dial telegraph of Dr. Siemens was invented in 1848, and was regarded as an important improvement upon any of the systems then existing. The principle of this apparatus is that of the automatic transmission of currents, or the self-acting make-and-break.

Let M and M′ (fig. 337) represent the two poles of an electro-magnet, and A the armature pivoted at a point D midway be-

tween the poles. A rigid arm H is attached to the armature, carrying a flexible spring h at its extremity, armed with a catch or hook, so arranged as to engage with the ratchet shaped teeth of the wheel R. The wires I L′ L complete the circuit of the battery B with the electro-magnet. Now whenever this circuit is closed, the poles of the magnet will attract the armature, causing it to turn upon the pivot D, and the hook on the spring h will slip over a tooth of the wheel R; but when the circuit is broken the spring F, acting upon the arm i, draws back the

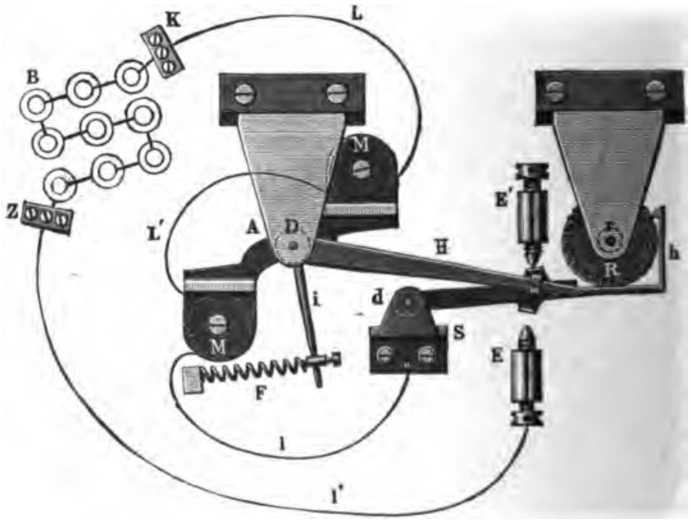


Fig. 338.

lever H to its former position, at the same time the hook on the spring h engages with a tooth of the wheel R and pulls it around a distance of one tooth. Thus every time the circuit of the electro-magnet M M′ is broken the wheel R advances a distance of one tooth. In Siemens's arrangement the movement of the lever H is itself caused to open and close the circuit by an ingenious device represented in fig. 338. It consists of a movable lever S, termed the shuttle, which lies underneath the lever H, and is pivoted at d. This is composed of a thin piece of metal, which is turned up into two little ears, on each side,

which, as the shuttle moves to and fro, strike against the adjustable screw stops E and E′, by which the movement is limited. The arm H passes between these ears, but has some little play, so that it cannot come in contact with both at the same time. The apparatus being arranged as shown in fig. 338, the action will be as follows: The spring F pulls the arm H downward

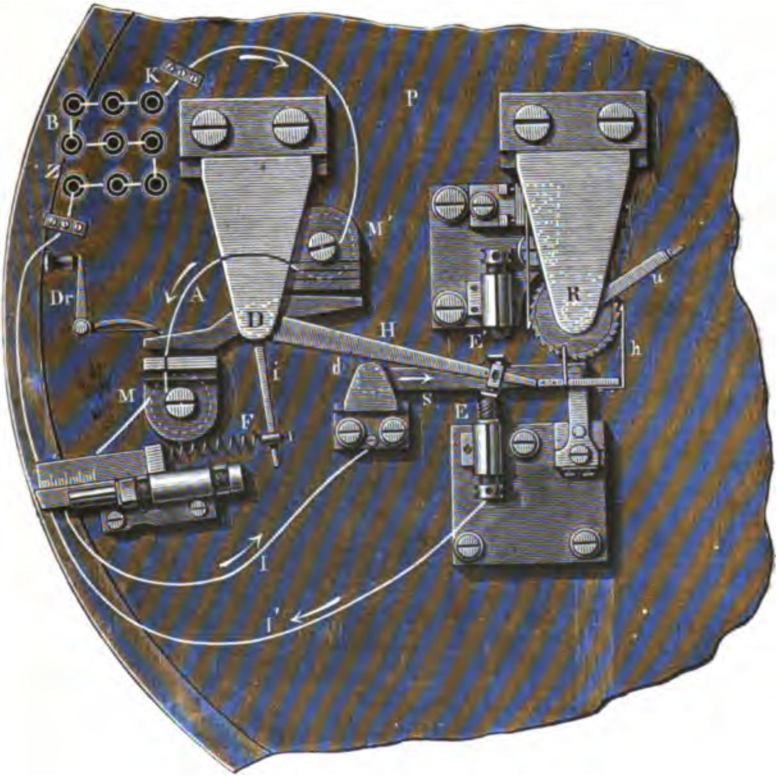


Fig. 339.

until it strikes one of the ears of the shuttle and forces it against the screw E. This closes the circuit and brings the magnet into action; it remains active until almost the completion of the stroke, when lever H strikes the opposite ear of the shuttle and lifts it, which breaks the circuit again, and the operation is repeated as long as the battery remains in action. Fig. 339

shows the application of this movement to the instrument, a revolving arm u being fixed upon the axis of the ratchet wheel R. A sectional view of the instrument is given in fig. 340, showing the manner in which the arm u revolves underneath the plate P P′. The manner in which the movement of the

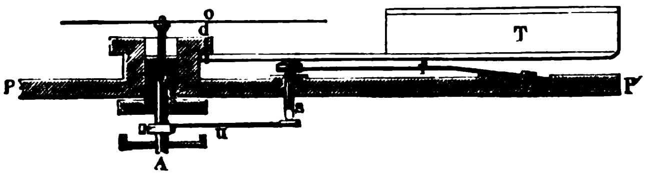


Fig. 340.

apparatus is stopped to indicate any particular letter is as follows: A circular keyboard is placed above the mechanism, as shown in fig. 341. Each key is marked with a letter or signal, and is provided with a pin s (fig. 340), which is caused to project downward when pressed upon by the finger, so as to

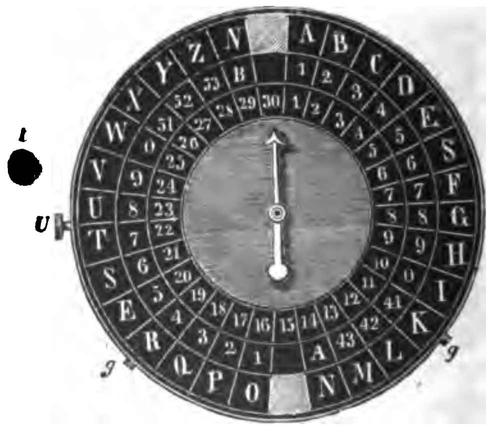


Fig. 341.

stop the revolution of the arm u. The latter, moreover, is so adjusted that at the moment it strikes against any one of the pins which happens to be depressed the circuit will always be broken at the shuttle. When the key T is released the spring

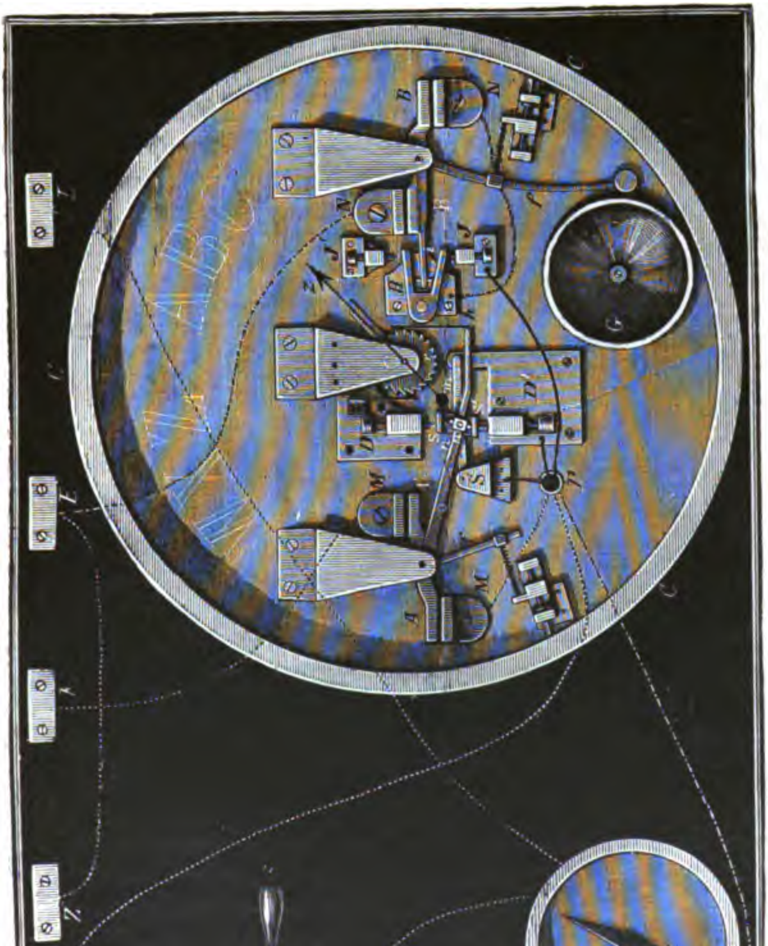


Fig. 342.

F (fig. 338) draws the arm H down, closes the circuit and causes the movement to recommence.

Fig. 342 is a plan view, showing the complete apparatus beneath the keyboard. The line wire is attached at L and passes, as shown by the dotted line, to the galvanometer G, and thence to switch S′, which is ordinarily turned on R, and thus directs the current to the self-acting alarm apparatus at J, and thence by N to the earth connection at E. The alarm apparatus being exactly similar in its action to the movement heretofore

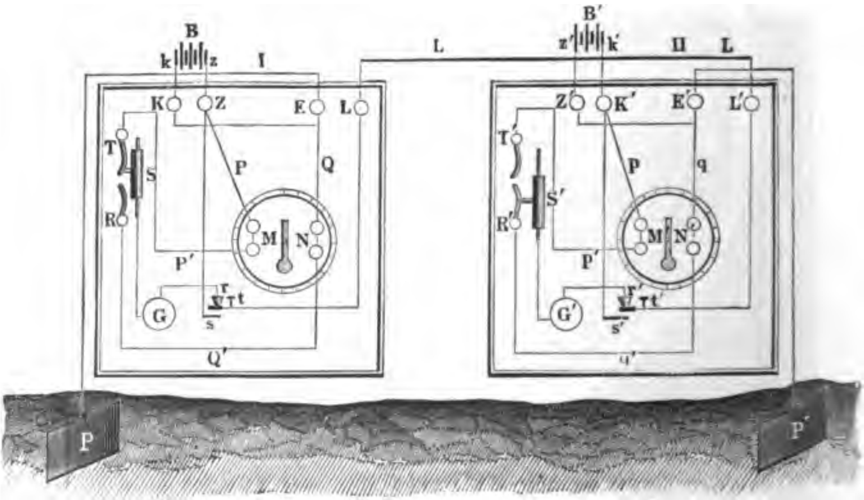


Fig. 343.

described, needs no further explanation. When a communication is to be received the switch S′ is turned on the point T, which conducts the main circuit by the way of D S, and the electro-magnet M M′ to the point K, which connects with one pole of the battery, the other pole Z being to the earth. The shuttle mechanism of both the sending and receiving instruments being now in circuit, the arm *u* of the sending instrument and the index hand Q of the receiving instrument must necessarily revolve in unison. When the circuit is broken by the stoppage of the arm *u* by the depression of a key at the sending

station, the receiving instrument will also stop at the same point. Fig. 343 shows the arrangement of connections for two stations, which will be understood without further explanation, as the letters of reference are the same as in the preceding figures. The commutator *r s t* serves to put the battery B in direct circuit between the line and the ground without passing through the instrument.

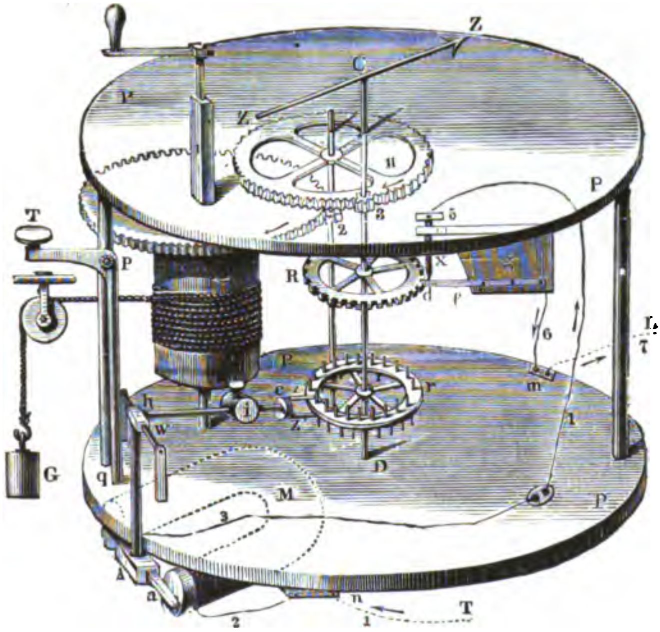


Fig. 344.

This apparatus was formerly employed to a considerable extent upon the German railway lines, and was found to operate in the most admirable manner. It has now been almost altogether superseded for this purpose by the Morse apparatus.

KRAMER'S APPARATUS.

The principle of Kramer's dial telegraph is quite similar in many respects to that of Siemens's, but it is considerably less complicated. The principle of a self-acting make-and-break is

employed in combination with a clockwork driven by a weight or spring, but a continuous current is employed, as on the American, and some of the German lines with the Morse apparatus.

The external appearance of Kramer's apparatus differs very little from that of Siemens's. It consists of a circular dial, having thirty keys arranged around its circumference, numbered from 0 to 29, inclusive. An inner circle is marked in corresponding sections with the letters of the alphabet, and a third circle, concentric with the others, contains a double row of numerals from 1 to 9, and some other characters and blanks.

The interior of the apparatus is shown in fig. 344. Two circular plates of metal, connected together by three posts near their periphery, constitute the frame of the instrument. The axis C of the pointer Z Z above the dial passes through these two plates. This axis carries an escape wheel *r* and another toothed wheel R; it is turned by the pinion 3, which is driven through the intervention of clockwork, by the weight G. The escapement *r* is formed by a horizontal wheel, upon the rim of which are sixty vertical steel pins, which alternately project upward and downward at equal distances from each other. The prongs of a steel fork *c z* lock into the pins, and are at such a distance from each other that when one prong touches the rim of the wheel on one side the succeeding pin can pass under the other prong. The fork is supported by the bell crank lever *h*, turning between upright bearings upon the axis *w*. A soft iron armature A is supported by the lower arm of the lever, opposite the poles of an electro-magnet M, which regulates the movement of the fork and escape wheel. The figure shows the armature attracted to the poles of the electro-magnet, which is the normal position of the apparatus when at rest.

The toothed wheel R, the spring *d*, and contact point *x* serve to regulate the closing and breaking of the circuit. The wheel has thirty teeth, and therefore the circuit is broken thirty times during each revolution by the lifting of the spring *d* from the contact point *x*. Fig. 345 shows the position of the spring in

relation to the toothed wheel when the circuit is open, and fig. 346 when it is closed.

When the electro-magnet attracts its armature a tooth of the wheel R lifts the spring *d* and interrupts the circuit. The

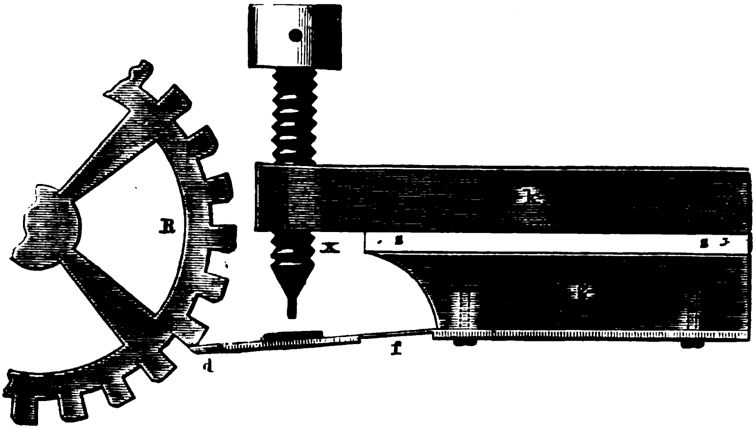


Fig. 345.

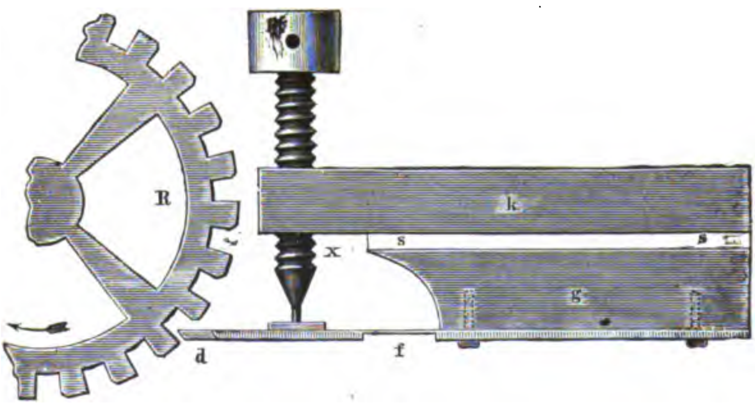


Fig. 346.

armature then falls off, depressing the fork and allowing another pin to escape, by which means the circuit is reëstablished between *d* and *x*, and so on indefinitely, the course of the current

being shown by the arrows and the figures 1, 2, 3, 4, 5, 6, 7. In this way the pointer keeps running round the dial until the clockwork runs down, but it is obvious that the motion may be arrested, either by breaking the battery circuit, in which case the armature falls off, and the fork escapement rests upon the upper surface of the escape wheel, or by arresting the pointer itself. The latter is the method employed when transmitting: the key above the dial corresponding to any letter being depressed, interposes a pin which stops the further progress of the pointer, as in Siemens's instrument, at a point when the circuit is open, as in fig. 345, and this, of course, causes the other instru-

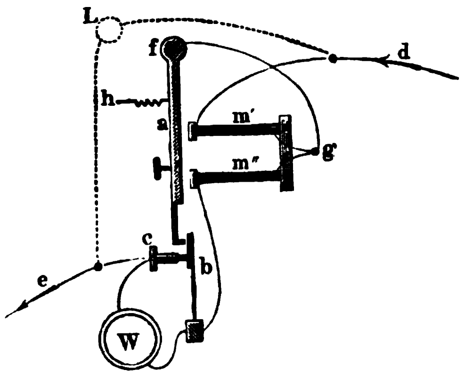


Fig. 347.

ment or instruments in the circuit to stop at the same letter. The pointer may be set by means of the button T, to bring it into unison with the sending instrument.

The alarm employed by Kramer is rung by the release of an armature from the poles of an electro-magnet. To provide against the possibility of the alarm failing to operate in consequence of the escape from the line to earth in the closed circuit system, Kramer has devised the ingenious arrangement shown in fig. 347. In front of the armature a contact screw *c* is pressed against by a flat spring *b*, so that when the armature *a* is attracted towards the poles of the electro-magnet m' m'', it comes in con-

tact with the spring just before the completion of its stroke and separates it from the contact screw. The armature is connected by a wire $f\ g$ to the middle of the coil wire of the electro-magnet; the line wire e is connected to the contact screw c; and between the spring b and the same line wire a resistance W is inserted equal to that of one coil of the electro-magnet.

The current arriving by the line wire d and passing in the direction indicated by the arrow, passes by way of $m'\ m''\ b$ and c to e, the resistance W being cut out by the spring b. The armature a is thereupon attracted, and as it descends makes contact with the spring b, thereby short circuiting one half the electro-magnet m'' and at the same instant breaks the circuit between b and c, thus throwing the resistance W into circuit, and leaving the total resistance between d and e unchanged. The armature is now held only by one pole m', and the spring h is so adjusted that on the slightest decrease in the magnetism of m' it exerts force enough to pull off the armature a.

WHEATSTONE'S MAGNETO-ELECTRIC DIAL APPARATUS.

This instrument was perfected by Wheatstone in 1858, being an improved form of the magneto-electric dial apparatus invented and patented by him in 1840. It is very largely used in Great Britain upon private telegraph lines, and to a great extent upon the less important government lines. Wheatstone's apparatus consists of two distinct parts, which are respectively termed the communicator and the indicator. Fig. 348 is a perspective view of the communicator. It consists of a small square box, upon the upper surface of which is a raised dial plate, surrounded by thirty equidistant keys radiating from the same centre. Upon the dial plate are marked the twenty-six letters of the alphabet, three points of punctuation and an asterisk; in an inner concentric circle are the nine numerals and a cross on each side. A pointer turning on an axis in the centre of the dial rotates in connection with the handle or crank which projects from the front of the box, and may be arrested at any letter, while the handle is being turned, by depressing one of the

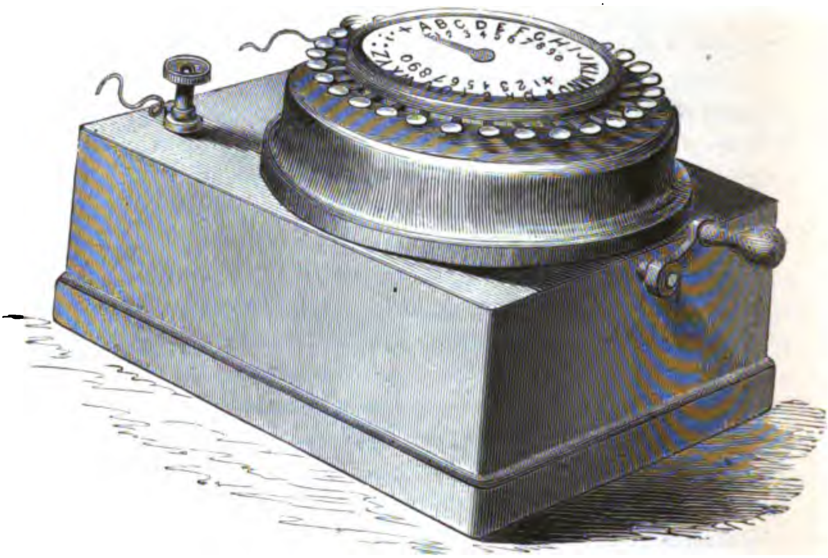


Fig. 348.

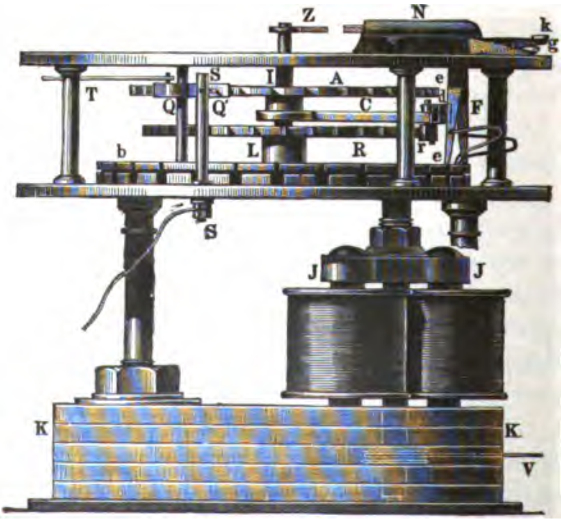


Fig. 349.

keys or buttons. Fig. 349 is a side elevation of the interior mechanism of the apparatus. K K is a fixed permanent horseshoe magnet, placed horizontally, upon the poles of which are fixed two soft iron cores, with their helices of insulated wire. On a vertical axis passing between these cores is placed a soft iron armature or inductor J J, which is caused to revolve by means of the pulley and band V, which is connected with the crank seen in fig. 348. When the armature revolves it induces alternate positive and negative currents in the helices, upon the principle of the apparatus described in Chapter XIII, fig. 81.

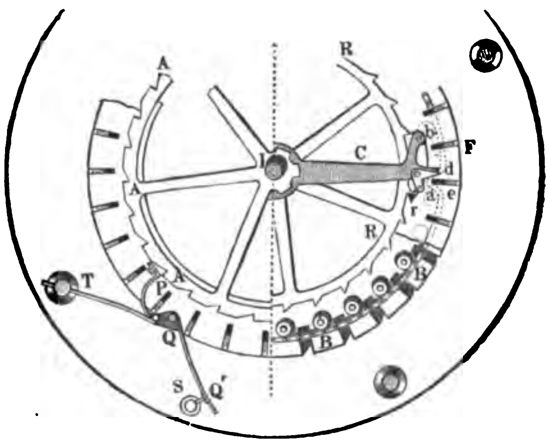


Fig. 350.

The shaft I is driven by a toothed wheel placed within the disc B on the hollow shaft L, to which the wheel B is attached. The indented periphery of the wheel A (fig. 350) acts upon an oscillating angular lever P, which terminates in a spring Q Q′, and acts as a circuit breaker, in connection with the stationary post S, through which the magneto-currents pass from the inductor J. Whenever the end of the lever P falls into a notch of the wheel A the spring Q′ is lifted from the post S and the circuit is momentarily interrupted.

In the plan view of the apparatus (fig. 350) a small endless

chain is shown passing around a series of rollers underneath the keys. Whenever a key is depressed, as shown at *g* in fig. 349, the arm *e*, which projects downward from the key, is pressed inward against the chain, as shown at *a* in fig. 350. As soon as any other key is depressed the chain is pulled straight under the first key and lifts it up. The action of each key is two-fold; it serves to arrest the pointer Z in its revolution, and to interrupt the circuit and cut off from the line the currents which would otherwise be produced by the revolution of the inductor J during the time in which the pointer is standing still. This is effected by the arm C (figs. 349, 350 and 351) attached to the

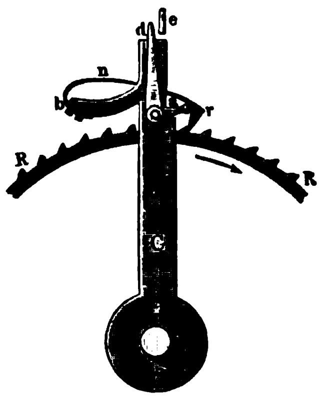


Fig. 351.

shaft I, which carries the pointer Z. This arm carries a bent steel spring *b n r* (fig. 351), which is provided with a hook or catch *r*. On the end of the arm C is also an angular lever *a d*, the short arm *a* of which has a pin projecting downward, in such a position that the spring *b n r* presses against it. When all the parts are in the position shown in the figure the wheel R revolves in the direction of the arrow, carrying with it the arm C, by means of the hook *r*. But when a key *e* is depressed, and thus thrown into the path of the lever *d* as it revolves, the latter comes in contact with it and is pressed back, thereby lifting the catch *r* and disengaging the arm C from the wheel R, the latter

continuing to revolve while the former remains stationary. If the key is released again the hook r engages with the nearest tooth of the wheel R, and the arm C together with the wheel A and pointer Z, moves forward again as before. Thus it will be seen that the movement of the magneto-inductor is entirely independent from that of the signaling mechanism, the arrangement being such that when the arm C is arrested by the depression of a key, the lever P is in a position to interrupt the circuit between Q′ and S.

Fig. 352.

The exterior of the indicator is shown in fig. 352, and its internal mechanism in fig. 353, in which one half of the system of electro-magnets is removed. The apparatus consists of two rectangular electro-magnets, one of which is shown at E, of small diameter, arranged parallel, and with their opposite poles facing each other. Two curved permanently magnetic bars A A and A_1 A_1, arranged upon an axis X X, constitute the common armature of the two magnets. The axis X X turns between screw points and has an arm projecting upwards, which supports one end of the axis of a small escape

wheel, the other end of this axis being supported in a piece a, which carries the indicating pointer or needle moving in front of the dial. Thus, in this instrument, the escape wheel is vibrated, and it is at the same time caused to rotate by means of two stationary hooks or catches r r. The wheel is prevented from skipping or being moved too far by stops b b.

The alternate positive and negative pulsations from the magneto-inductor passing through the electro-magnet E continually reverse its polarity, and cause alternate attraction and repulsion

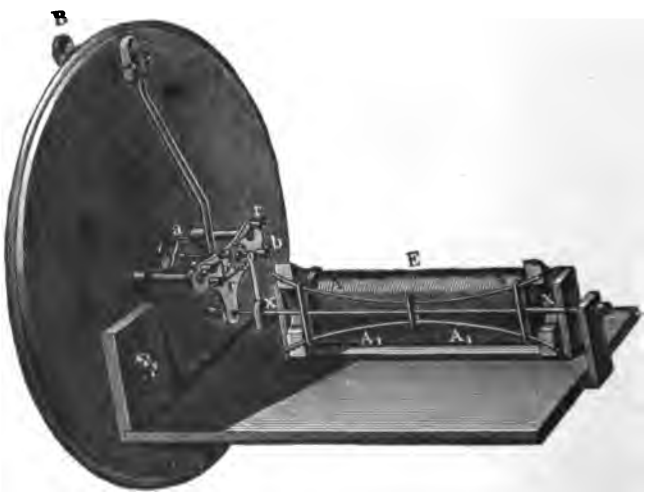


Fig. 353.

of the little steel magnets A A and A_1 A_1. This movement is transferred to the escape wheel and causes it to revolve step by step, as in other instruments of this kind. By means of the button B, which acts upon the escape wheel by means of a fork, the needle may be set to zero at pleasure without the aid of the current.

The mechanism of this apparatus is constructed with such precision that it operates in the most perfect manner, even when the inductor is turned very rapidly. There are probably a

Fig. 354.

greater number of these instruments now in use than of any other dial telegraph ever invented.

SIEMENS AND HALSKE'S MAGNETO-ELECTRIC DIAL TELEGRAPH.

This convenient and trustworthy apparatus was first constructed many years ago for the use of the Bavarian telegraph

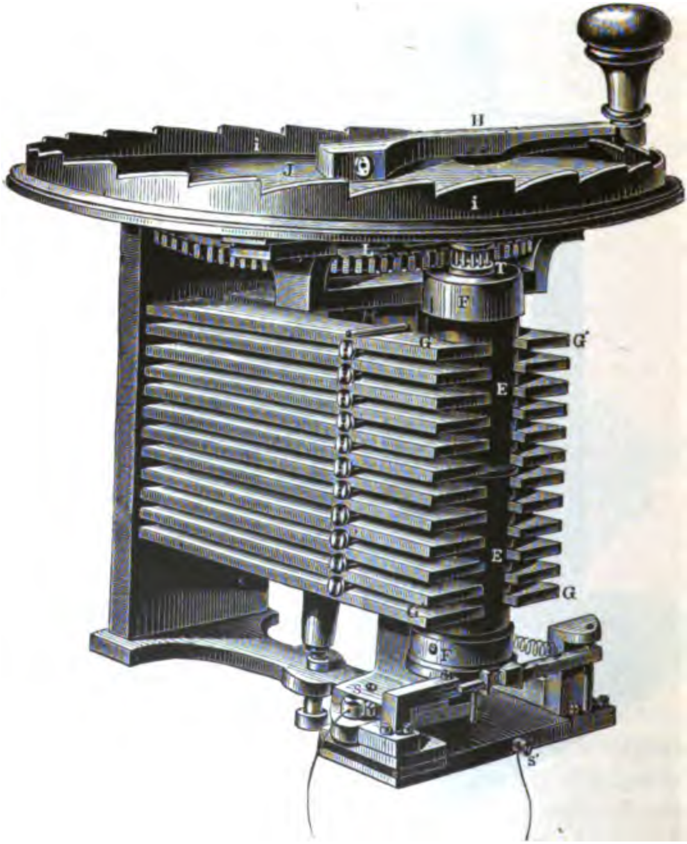


Fig. 355.

lines. It is largely employed on the railway lines of Russia, and on the municipal lines of some of the principal European cities.

The apparatus consists of a battery of permanent magnets,

between the poles of which revolves a coil of insulated wire, wound upon a soft iron armature. This motion develops alternate positive and negative currents, which traverse the line and pass through the coils of an electro-magnet at the receiving station, causing its armature to vibrate and turn an escape wheel and pointer. Fig. 354 represents an external view of the complete apparatus, which is contained in a case of wood or metal. H is a handle, which, in operating the apparatus, is turned round

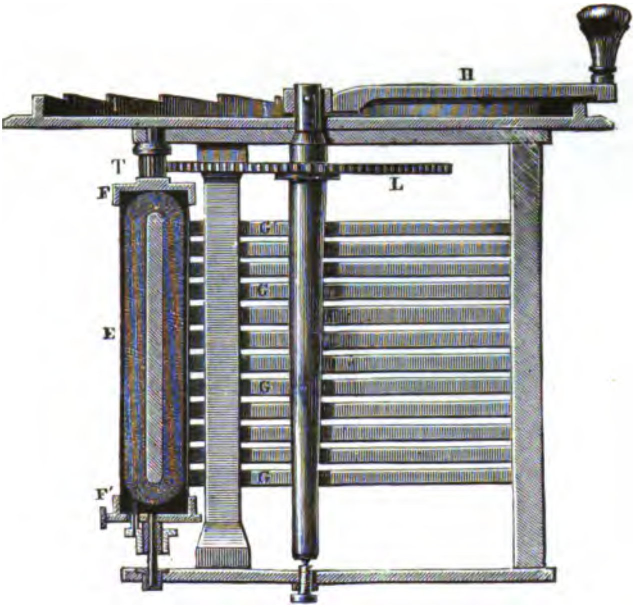


Fig. 356.

from letter to letter, the letters being marked on the horizontal dial plate J, stopping always against the tooth opposite the letter to be indicated; and 2 is the dial of the indicator, which corresponds in its arrangement with that of the transmitter, the motions of the pointer following accurately those of the handle of the instrument which is operating it.

Fig. 355 and fig. 356 show the internal mechanism of the transmitter. The metal disc J, with inclined or ratchet shaped

teeth i upon its rim, is fixed upon the top of the compound magnet, which consists of a number of permanent magnets G G G′ G′, screwed to an upright soft iron plate n (fig. 357). Between the poles of this system of permanent magnets is placed a cylinder of soft iron E, which serves as the keeper or armature of all the magnets. This arrangement is universally known as the Siemens armature, and is of very peculiar construction. It is channelled longitudinally with two deep broad grooves on opposite sides, which gives it an I shaped section (best seen in fig. 357). A coil of fine insulated wire is wound longitudinally within these grooves, as seen in fig. 356. The whole armature is supported by brass caps F F′ in pivots above and below. Above the armature coil the pinion T gears into the toothed wheel L, which turns upon its axis by means of the handle H above the disc J. The proportion between the teeth of the

Fig. 357.

wheel and that of the pinion is such that one revolution of the wheel causes the pinion to revolve thirteen times, reversing the magnetism along the whole length on each side of the armature, and thereby inducing in the coil, if the circuit is closed, thirteen positive and thirteen negative electrical pulsations of equal and opposite magnetic effect. When the coil is turned half round on its vertical axis the polarity of the armature is also changed, and a magneto-electric current induced in the armature coil in one direction, and upon turning it half a revolution further round, so that it takes up its former position, a current in the opposite direction is induced. The ends of the coil of wire which are attached to the brass caps are connected, one to the earth plate and the other to the coils of the electro-magnet of the indicator, and thence to the line.

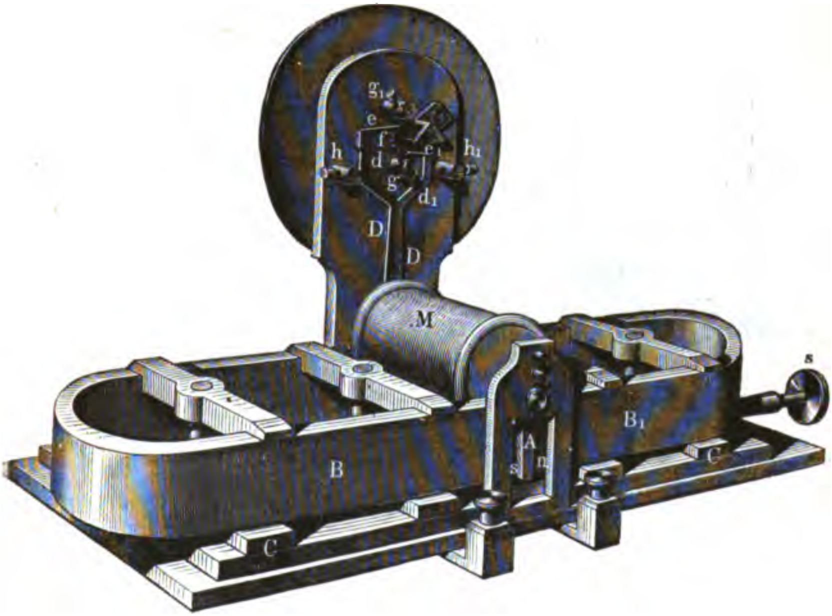


Fig. 358.

The interior of the indicator is shown in perspective in fig. 358, and in front elevation in fig. 357. The coil or helix of in-

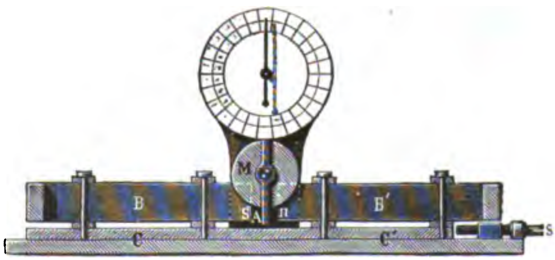


Fig. 359.

sulated wire M is fixed, but its core is free to turn within it, being mounted between screw points. The ends of the core are provided with soft iron continuations projecting downwards, one

of which is seen at A, and these are free to vibrate between the opposite poles of two horizontal permanent magnets B and B_1. The front end of the oscillating core carries an arm D projecting upwards, which works the indicator needle or pointer by means of a double acting escapement, shown in fig. 358, but more clearly in fig. 360. In the latter figure *f* is the escape wheel on

Fig. 360.

the axis of the pointer and having thirteen ratchet shaped teeth. At the end of the vibrating arm D are two branches *d d'* forming a sort of fork, and these branches are provided with thin flexible steel springs *e* and *e'*, carrying hooks which catch into the teeth of the ratchet wheel *f*. The ratchet wheel having thirteen teeth, when the armature oscillates from right to left, or from left to right, the wheel advances half a tooth; and in order that the pointer may traverse the whole circumference of the dial, the armature must oscillate thirteen times in each direction. This is provided for by arranging that exactly that number of reverse currents or pulsations shall be transmitted from the sending station when the handle of the transmitter is turned once round the dial. The polarity of the core within the helix M is correspondingly reversed, causing it to be alternately attracted and repelled by the permanent magnets B and B_1, thus causing the oscillation of the arm D and operating the pointer of the indicator. The adjustable screw stops *g g'* limit the motion of the arm D, and prevent the skipping of the wheel.

The call bell or alarm used with this instrument is seen at

the top of the case in fig. 354. The principle is the same as that of the polarized relay described on page 509. A continuation of the armature carries a hammer, which vibrates between two bells. A switch seen beneath it, when turned to W, connects the line to the alarm, and when turned to Z connects it with the indicator.

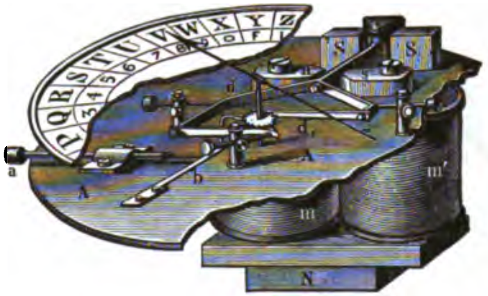


Fig. 361.

An improved and more recent form of the indicator is shown in fig. 361. This is also constructed upon precisely the same principle as the polarized relay above alluded to, the escapement being similar to that shown in fig. 358 and fig. 360. It will be readily understood without further explanation.

The general arrangement of the connections is shown in fig. 362. E is the revolving armature or inductor, and M the coil of the indicator magnet. The line wire enters at L, and when the apparatus is not in use, is turned through the alarm direct to the earth by placing the switch Y upon W. By changing the switch to Z the inductor and indicator are put in circuit.

HAMBLET'S MAGNETO-ELECTRIC DIAL TELEGRAPH.

This instrument has found extensive employment upon private and municipal telegraph lines in the United States. In its general principle it is not unlike Wheatstone's. The apparatus is placed upon a small table, and so arranged that the inductor may be driven by a treadle, leaving both hands free to manipulate the keys, by which means the practical speed of the instru-

ment is materially augmented. The indicator is not essentially different from the later form of Siemens and Halske's, shown in fig. 361. The whole apparatus operates in a highly satisfactory manner. Very similar instruments are constructed by Welch & Anders, of Boston, having a Siemens's armature for an inductor, and a piano keyboard operating upon a cylinder, as in Froment's instrument, and provided with an ingenious attachment for opening the inductor circuit and simultaneously putting the line to earth during the stoppage of the transmitting cylinder caused by the depression of a key.

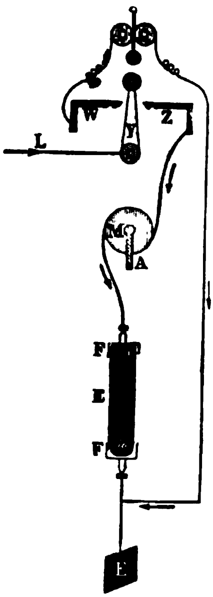


Fig. 362.

In the United States, dial instruments have been but little used except for private lines, and for this work they have within the past four or five years been almost entirely superseded by the improved and convenient type-printing instruments which have been designed for this purpose, and of which we shall give some examples in a following chapter.

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[From the *New York Herald*, Thursday, November 27, 1884.]

DYNAMO-ELECTRICITY.

Several attempts have recently been made to bring together in a single book the hitherto widely scattered fragments of our dynamo-electricity and dynamo-electric machinery. One of the most successful of these is by Mr. George B. Prescott, whose work is published, with 545 illustrations, by Messrs. Appleton & Co. When Faraday, in 1830, made the great discovery that a galvanic current is capable of inducing other galvanic currents in neighboring wires without actual contact, he predicted that others would make the power thus brought to light "available for very important purposes." Mr. Prescott's book abundantly shows how this prediction has been verified. The first dynamo-electric machine, which was constructed by Faraday in 1831, was able to give forth only a very small spark, scarcely perceptible. But everybody is familiar with the wonders of the electric light, which has been made to illuminate large areas, with a power exceeding that of a hundred thousand candles. Mr. Prescott clearly describes the production of the electric light, the progress made in its practical application, and all the latest improvements by Brush, Siemens, Gramme, Edison, Maxim, Swan, Bernstein and other inventors. He also goes quite fully into the subject of the electrical transmission of power and modern electro-motors, including the electric railways devised by Dr. Werner Siemens, Mr. Thomas A. Edison, Mr. Stephen J. Field, that operated by accumulators at Le Breuil-en-Auge, France, as also electric railways for transporting despatches, and the device of French engineers for ploughing by electricity. Combined with the historic and descriptive portions of Mr. Prescott's treatise, there are lucid discussions of the theory of dynamo-electric generators, electrical measurements and formulas on the subject of the efficiency of motors. The problem of producing electricity on a large scale and within economic limits is not yet fully solved. Over sanguine inventors have sometimes met with not a little disappointment, as might have been expected when speculation outran scientific research. But the publication of works like the one before us and others we shall mention will do much to burst the bubbles of extravagant expectation and clear the field for future inquiry and discovery.

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